17TH EDITION

2024
TECH TRENDS
REPORT

Future Today
Institute

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THE YEAR AHEAD: TECH SUPERCYCLE

The theme for our 2024 report is Supercycle. In economics, a "supercycle" refers to an extended period of booming demand, elevating the prices of commodities and assets to unprecedented heights. It stretches across years, even decades, and is driven by substantial and sustained structural changes in the economy.

We believe we have entered a technology supercycle. This wave of innovation is so potent and pervasive that it promises to reshape the very fabric of our existence, from the intricacies of global supply chains to the minutiae of daily habits, from the corridors of power in global politics to the unspoken norms that govern our social interactions.

Driving this seismic shift are the titans of technology and three of their inventions: artificial intelligence, biotechnology, and a burgeoning ecosystem of interconnected wearable devices for people, pets, and objects. As they converge, these three macro tech segments will redefine our relationship with everything, from our pharmacists to our animals, from banks to our own bodies. Future Today

Institute's analysis shows that every technology—AR/ VR/ XR, autonomous vehicles, low Earth orbit satellites, to name a few—connects to the supercycle in some way.

The ramifications are stark and undeniable. As this tech supercycle unfurls, there will be victors and vanquished, those who seize the reins of this epochal change, and those who are swallowed whole. For business leaders, investors, and policymakers, understanding this tech supercycle is paramount.

In this 17th edition of FTI's annual Tech Trends report, we've connected the supercycle to the nearly 700 trends we've developed. Our research is presented across 16 technology and industry-specific reports that reveal the current state of play and lists of influencers to watch, along with detailed examples and recommendations designed to help executives and their teams develop their strategic positioning. The trends span evolutionary advancements in well-established technologies to groundbreaking developments at the forefront of technological and scientific exploration. You'll see emerging epicenters of innovation and risk, along with a preview into their transformative effects across various industries.

We've visually represented the tech supercycle on the report's cover, which is an undulating image reminiscent of a storm radar. Vertical and horizontal lines mark the edges of each section's cover. When all 16 section covers converge, the trends reveal a compounding effect as reverberating aftershocks influence every other area of technology and science, as well as all industries.

It's the convergence that matters. In isolation, trends offer limited foresight into the future. Instead, the interplay of these trends is what reveals long-term change. For that reason, organizations must not only remain vigilant in monitoring these evolving trends but also in cultivating strategic foresight—the ability to anticipate future changes and plan for various scenarios.

Our world is changing at an unprecedented rate, and this supercycle has only just begun.
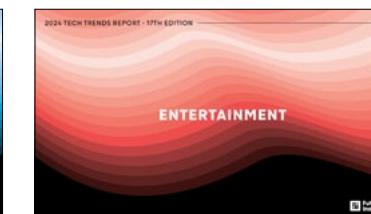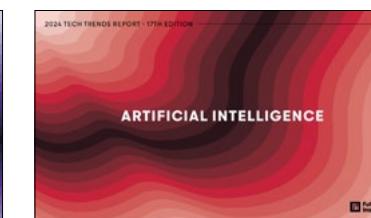
Amy Webb
Chief Executive Officer
Future Today Institute

FUTURE TODAY INSTITUTE'S 2024 TECH TREND REPORT
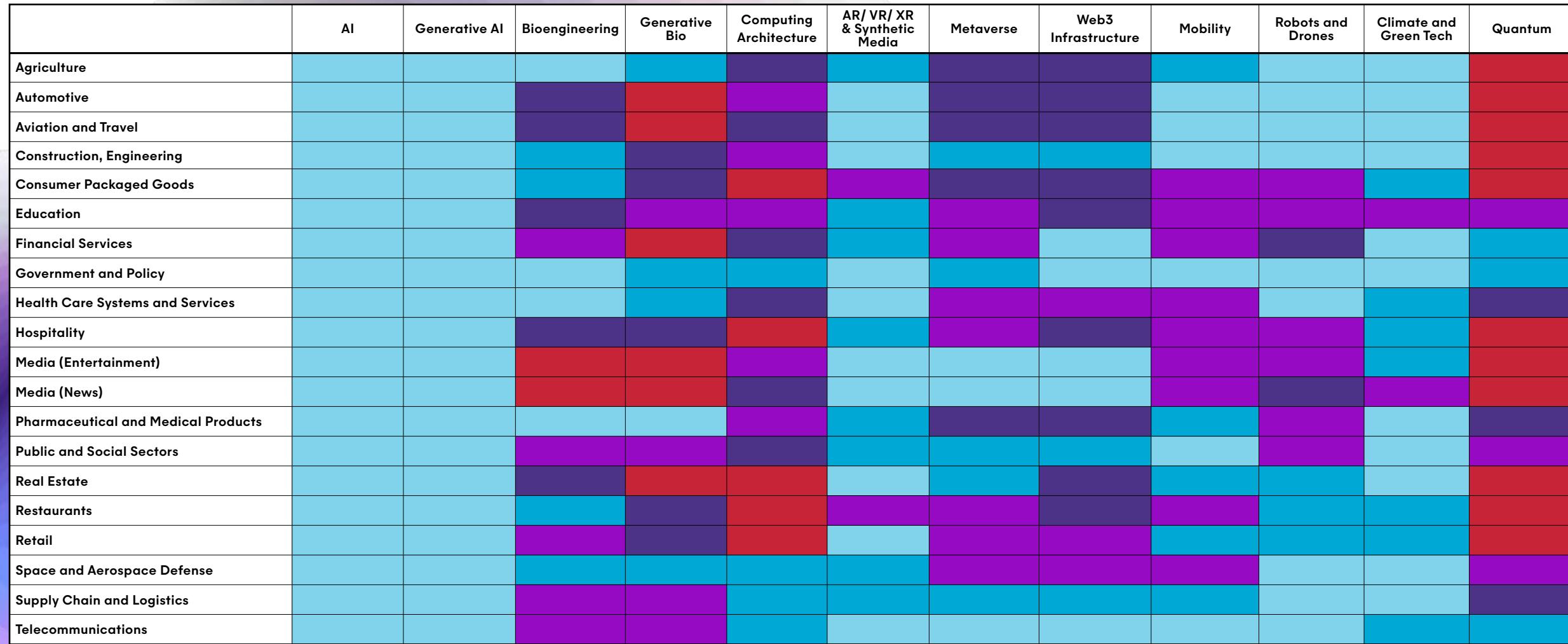
Our 2024 edition includes nearly 700 trends, which are published individually in 16 volumes and as one comprehensive report with all trends included.

Download all sections of Future Today Institute's 2024 Tech Trends report at **http://www.futuretodayinstitute.com/trends.**

IMPACT OF TRENDS ON YOUR INDUSTRY

Near-Term Relevance ▢▢▢▢▢ **Long-Term Relevance**

	AI	Generative AI	Bioengineering	Generative Bio	Computing Architecture	AR/ VR/ XR & Synthetic Media	Metaverse	Web3 Infrastructure	Mobility	Robots and Drones	Climate and Green Tech	Quantum
Agriculture												
Automotive												
Aviation and Travel												
Construction, Engineering												
Consumer Packaged Goods												
Education												
Financial Services												
Government and Policy												
Health Care Systems and Services												
Hospitality												
Media (Entertainment)												
Media (News)												
Pharmaceutical and Medical Products												
Public and Social Sectors												
Real Estate												
Restaurants												
Retail												
Space and Aerospace Defense												
Supply Chain and Logistics												
Telecommunications												

17TH EDITION · 2024 TECH TRENDS REPORT

EXECUTIVE SUMMARY

Future Today Institute

2024 TRENDS

Trends are what we can know about today and are based on data and evidence. This year's trend report covers hundreds of technology trends across various industries and categories.

TRENDS

ARTIFICIAL INTELLIGENCE

While the hype continues, now is the time to prepare.

AI is a transformative, general-purpose technology with the potential to influence entire economies and alter society. From multi-modal AI to self-improving agents and wearables with on-board assistants, the ecosystem is rapidly changing. While AI advancements promise to reshape our world, emerging trends highlight unprecedented risks, underscoring the need for preparedness, governance, and alignment.

WEB3

Quiet developments and new regulations grow Web3.

While the industry reeled from failures and bankruptcies over the last year, developers have continued to develop new capabilities and features, moving ever closer to real-life practical applications for Web3. As regulations are on the horizon to be implemented in 2024, this could be a year of inflection, bringing Web3 from the experimental and theoretical to cold hard business cases.

METAVERSE & NEW REALITIES

Developments indicate a possible inflection point.

Apple's new headset leverages AI to overlay digital onto reality, representing a pivot from fantasy metaverses to real-life applications that may signal maturity. Meanwhile, complementary features to enhance virtual experiences are being developed. Though device costs are an ongoing barrier, integrating AI and XR creates fundamental synergies, potentially marking the watershed moment the industry has been waiting for.

BIOENGINEERING

Brace for impact in this breakthrough year.

Recent breakthroughs have accelerated the convergence of biology, information systems, and advanced platforms, and attention has been focused on generative AI. Very soon, that focus will shift to generative biology, where AI models will lead to the creation of novel molecules, drugs, materials, and living organisms. While biotech promises to reshape our world, it also requires preparedness and governance.

ENERGY & CLIMATE

Emerging and tested tech comes together for progress.

As the effects of climate change become more dire, governments are considering a more exotic set of technologies to combat the situation. Solar geoengineering, ocean chemistry manipulation, and domed cities are all concepts that gained significant traction in 2023. Meanwhile, significant gains have been made in enabling infrastructure for renewable energy, focusing on smart grids, energy storage, and carbon tracking.

MOBILITY, ROBOTS & DRONES

Challenges remain for electrification and autonomy.

Consumers are adapting to electric and semi-autonomous vehicles and those that collect increasing data. At the same time, battery technology is increasing, enabling vehicles, robots, and drones to perform longer. The rise of these machines suggests a future where they supplement and replace human tasks, highlighting a shift towards a more efficient, increasingly monitored work environment.

TRENDS

COMPUTING

AI is transforming human-computer interaction.

AI is changing what is possible in form factors, challenging underlying computing architecture. Researchers are pursuing energy-efficient architectures by reverse engineering the complex biological efficiencies of the human brain. As AI facilitates more intuitive communication, the technology could blend more seamlessly into human experiences, with computing centered directly around people rather than devices.

BUILT ENVIRONMENT

Automation and data collection transform practices.

In an industry used to following traditional practices, the past years have upended decade-old norms. Such shifts can provide critical solutions to new questions and signify a turning point that redefines industry standards and operational efficiency. This pivotal moment underscores the need for strategic adaptation, heralding a reinvention phase in response to evolving demands and technological advancements.

NEWS & INFORMATION

The news ecosystem hits an inflection point.

Emerging technologies like generative AI are shaping the future of content creation, distribution, and monetization. New applications of AI are reshaping the media value change and forging new consumer behaviors for information search and discovery. In the year ahead, the initial frenzy of ChatGPT prompt hacking and product launches based on large language models will fade, but the information ecosystem will never be the same.

HEALTH CARE & MEDICINE

The barrier between digital and biological is vanishing.

The merging of digital and biological worlds enables a whole new range of treatments, the most exciting being cells within our bodies that can produce medication in response to external stimuli. Conversely, cyberbio-malware creates new, existential threats to our health that we are unaware we need to protect ourselves against. Both developments have the potential to upend the pharmaceutical and healthcare industry completely.

FINANCIAL SERVICES & INSURANCE

Modernization is slow, but consumers are ready to run.

The financial services sector, dominated by legacy giants, is facing a critical juncture where embracing technology like open banking, digital identity, and blockchain is not just advantageous but imperative. This industry must shift from reactive to proactive, underscoring the importance of anticipation and preparedness in navigating the future of the financial and insurance industries.

SPORTS

Analytics and customization are transforming sports.

Technology is enhancing the capabilities of managers, coaches, athletes, and fans. Teams and leagues are seeing progress in scouting, training, performance analytics, and rehabilitation thanks to tools like mixed reality, computer vision, and AI. Smarter stadiums offer unique, immersive experiences, driving engagement and revenue streams that support further improvements in a game's quality and spectator experiences.

TRENDS

SPACE

Space exploration is entering a new era.

Defined by old geopolitical rifts and new spacefaring nations, this emerging era goes beyond past dynamics to involve a broader constellation of smaller nations and private enterprises, all enabled by the decreasing cost of space access. With lowered launch costs, zero gravity could unlock scientific discoveries previously impossible. The dream of a multi-planetary humanity stirs deep questions about our priorities.

HOSPITALITY & RESTAURANTS

Tech-driven efficiency can't replace personalization.

Contactless payments, immersive pre-experiences, augmentations that recognize a guest's personalized needs upon entering the premise, automated back-of-house functions offer opportunities for owners and operators to capitalize on that can provide elevated experiences and a reduction in overhead costs—but human workers might hold these positions, driving an ongoing tension between efficiency and a personal touch.

SUPPLY CHAIN & LOGISTICS

Real-time data and instant everything shape new terrain.

Regional instability, materials disruptions, manufacturing relocation, and labor tensions create hardship for businesses and manufacturers trying to bring their goods to consumers, who are also becoming more demanding. As businesses strive to meet these demands, they will be compelled to rethink their strategies, technologies, and workflows, marking a pivotal moment in the report on industry trends.

ENTERTAINMENT

AI's impact on live entertainment is just beginning.

Taylor Swift's concert film demonstrated that secondary live experiences resonate deeply. Add to that haptics, holographic transmission in real-time, and climate considerations that have consumers looking for local options, and a whole new world of performance experiences opens up. These developments create completely new ways to engage with content and opportunities for new business models.

2024 UNCERTAINTIES

Uncertainties represent what we cannot know—and identifying them can reduce the risk of blind spots down the road. In this year's report, we highlight five top uncertainties that will shape 2024.

UNCERTAINTIES

01

How quickly will AI revolutionize business, and in what ways?

JUMP TO UNCERTANTITY 1

02

What global challenges will bioengineering be able to address?

JUMP TO UNCERTANTITY 2

03

How will countries and businesses commit to decarbonization?

JUMP TO UNCERTANTITY 3

04

How will humans prioritize their work environments in the future, and what will these preferred workplaces look like?

JUMP TO UNCERTANTITY 4

05

In the context of increasing protectionism and geopolitical tensions, what is the future of the global chip manufacturing industry?

JUMP TO UNCERTANTITY 5

01

How quickly will AI revolutionize business, and in what ways?

UNCERTAINTIES

How quickly will AI revolutionize business, and in what ways?

Stratification Scales by Function or Task

GET THE DETAILS

Stratification by Industry

GET THE DETAILS

AI Scales Up for Consumers

GET THE DETAILS

Efficiency Optimization in the Back Office

Bolstered Productivity and Performance

Cautious Scaling in Complex Industries

Agile Scaling in Less-Regulated Industries

AI Serves as a Creative Playground

A Revolutionary Consumer-Facing Assistant

UNCERTAINTIES

Stratification Scales by Function or Task

AI scales along two distinct trajectories: by function or by task. Functional scaling involves embedding AI into key business operations, like accounting or IT, to enhance productivity. Conversely, task-based scaling increases efficiency for routine activities like email, leading to workforce streamlining. Both offer unique advantages for leaders, who must choose between broad operational transformation or targeted task refinement.

SCENARIO 1

Efficiency Optimization in the Back Office

AI emerges as a linchpin, enhancing efficiency for back-office operations like calendaring and leading to a cascade of broader organizational and cultural shifts. But there are human capital implications: As AI takes root, the workforce gradually contracts.

With efficiency gains, companies reconsider budgets, diverting funds from labor to tech. This shift fosters a culture of innovation, as employees are reassigned to more strategic, creative, or complex tasks that AI can't easily replicate. But it also will require companies to reevaluate talent strategies, prioritize adaptability and technical proficiency, and expand HR departments to include upskilling programs and change management.

SCENARIO 2

Bolstered Productivity and Performance

Integrating AI into the business ecosystem results in meaningful workforce reduction, as the tech can tackle work that previously required multiple humans.

Management adapts to overseeing hybrid teams of humans and AI, fostering collaboration and redefining performance metrics. Money previously allocated for salaries and benefits is redirected toward technology investment, research, and development, potentially driving further innovation. Ultimately, AI leads to more informed decision-making, risk assessment, and predictive analytics, and businesses tailor their AI solutions to specific departmental needs to gain competitive advantages.

UNCERTAINTIES

Stratification by Industry

As AI matures, its scalability pivots around industry-specific applications. The speed with which AI scales across certain industries is a function of technological receptivity and reflects the regulatory landscapes that govern them. Business leaders must carefully measure tradeoffs between these two challenges, calibrating their AI integration strategies to align with industry characteristics and regulatory confines.

SCENARIO 1

Cautious Scaling in Complex Industries

Sectors like financial services and health care stand to gain improved productivity and efficiencies as AI leaders by processing vast data streams and achieving decision-making acumen beyond human speed. However, lagging regulatory updates temper this progress.

Slower to replace the nuanced judgment of human experts with AI systems, businesses take a more deliberate scaling strategy. They invest in AI R&D to create more sophisticated models built on equitable data training. Their cautious approach extends to data privacy and security, as they implement strong measures to safeguard sensitive information.

SCENARIO 2

Agile Scaling in Less-Regulated Industries

Industries less encumbered by compliance hurdles—such as consumer packaged goods and retail—are quick to capitalize on AI's potential. It becomes a dynamic catalyst for innovation, enabling rapid ideation and deployment of new products and services.

AI's ability to analyze vast amounts of data in real-time is leveraged to personalize customer experiences, from tailored product recommendations to enhanced service interactions. It also creates supply chain resilience by predicting demand, optimizing inventory, and identifying potential disruptions.

UNCERTAINTIES

AI Scales Up for Consumers

Two primary use cases of AI alter everyday life. The first is through creative and experimental applications that introduce a sense of play and innovation to regular activities. They are reshaping entertainment, social media, and online engagement by providing novel, personalized experiences. The second sees AI as a practical assistant, seamlessly integrating into daily routines to manage tasks, offer recommendations, and streamline decisions. This form of AI is becoming a dependable extension of personal efficiency. These manifestations of AI highlight its versatility and growing significance in shaping consumer behavior.

SCENARIO 1

AI Serves as a Creative Playground

For consumers, AI is more about novelty and entertainment than utility. Students integrate generative AI into their projects, pushing the boundaries of creativity and academic exploration. Social media enthusiasts use it to embellish their online personas and captivate their followers.

Consumers now expect more interactive and personalized digital experiences across all platforms, influencing a shift in how products and services are designed and marketed. At the same time, the digital divide is more pronounced as a broader segment of the population becomes adept at navigating and manipulating digital environments and tools.

SCENARIO 2

A Revolutionary Consumer-Facing Assistant

The AI assistant transcends its fledgling origins to become an essential element of daily life. It simplifies complex tasks and executes functions with a level of access and autonomy that mirrors human assistance. Consumers find tangible ease in their routines as AI assistants manage calendars, make informed purchases, and even anticipate needs before they arise.

The downside: The role of AI in decision-making processes raises ethical questions, especially if these systems begin to influence areas like personal relationships, employment opportunities, and even legal decisions.

OPPORTUNITIES & THREATS

THREATS

1 Workforce disruption
As AI takes on more responsibilities, companies must manage job losses and reskill employees to avoid negative backlash.

2 Regulatory non-compliance
Strict governance in regulated sectors can curb AI innovation/adoption if transparency, accountability, and ethical standards are not upheld.

3 Data privacy issues
As AI leverages increasing amounts of consumer data, rising public concern around data privacy may warrant increased regulation and standards around data use.

OPPORTUNITIES

1 Increased productivity and efficiency
AI implementation in back-office and core business functions can result in exponential productivity gains, superior efficiency, and cost reductions.

2 Enhanced data-driven decision-making
AI will provide business leaders with previously inaccessible insights, predictive analytics, and risk assessments to inform strategy and planning.

3 Competitive differentiation
Customized enterprise AI solutions present opportunities to develop proprietary platforms, hyper-specialized tools, and new business models that distinguish an organization.

STRATEGIC QUESTIONS

1

Are you mainly focused on leveraging AI in your organization for functional efficiency, task-based productivity gains, or both? What are you doing to build those strategies?

2

Do you have the data governance foundations and AI accountability measures to comply with existing and emerging regulations?

3

How might your offerings need to shift as consumer and business buyer expectations evolve?

4

How might emerging AI systems create a compounding effect for your business? Is there a part of your business that could be vastly improved or optimized if a component or compound could be altered slightly?

5

How will third-party AI assistants change consumer expectations of your products and services?

02

What global challenges will bioengineering be able to address?

UNCERTAINTIES

What global challenges will bioengineering be able to address?

Better Living

GET THE DETAILS

Infrastructure Resilience

GET THE DETAILS

Securing Agricultural Infrastructure

GET THE DETAILS

Subscribe or Die

The Never Retiring Workforce

Widening Societal Gap

Self-Sustaining Highways
(The End to Infrastructure Bills?)

World War Food

Community-Focused Food

UNCERTAINTIES

Better Living

Bioengineering initiatives and research present a change in our approach to health care and even aging. Researchers use generative biology to create new therapeutic compounds and test the viability of gene editing. That work results in better drugs, personalized treatments, engineered tissues, and alternatives to one-size-fits-some medicine. Experiments are underway to alter genetics to cure ailments and diseases, with success already being achieved in hearing loss reversal and sickle cell treatment. Scientists leverage animal alternatives as they work to enhance limb, organ, and joint regenerative capabilities.

SCENARIO 1

Subscribe or Die

Health care shifts from reactively treating sickness and diseases to proactively addressing potential health issues before they emerge. With the goal of making up for any future lost "reactive" revenues, the largest health care systems use M&A to join the bioengineering landscape as facility providers and treatment hubs. People subscribe to bio-based services, which they must use to continue getting access to health-promoting and anti-aging solutions. Big Bio creates the ultimate subscription package: Continue paying, or face an untimely alternative.

SCENARIO 2

The Never Retiring Workforce

Economic conditions have not drastically improved for Millennials and Gen Z, who cannot afford to retire. Thanks to preventative medicine, genetic surgeries, and new therapies, the life expectancy of Americans spiked from 77 to 115 years. Many older individuals feel physically and mentally capable of working indefinitely, while younger generations face a bottleneck in career advancement.

The implications are profound, and not just in the US. HR professionals and labor economists prompt a reevaluation of career trajectories, retirement planning, and intergenerational equity, hoping to stave off a collapse.

UNCERTAINTIES

Infrastructure Resilience

Our infrastructure is no longer crumbling and fragile. By creating new compounds and modifying existing ones, bioengineering significantly enhances construction materials' strength, durability, and flexibility while reducing reliance on harmful chemicals and petroleum-based compounds. Compounds that self-heal extend the lifespan of infrastructure by autonomously repairing damage. New materials, designed with generative biology, result in "living" buildings engineered with sustainable, organic materials.

SCENARIO 1

Widening Societal Gap

As bioengineering technologies mature and scale, the demand for traditional construction and maintenance services wanes. Construction firms that don't adapt— struggle, and those specializing in bioengineered solutions—thrive.

While new homes are increasingly constructed with these innovative materials, integrating them into existing homes proves financially prohibitive for many homeowners. A two-tier infrastructure landscape emerges, where newer developments boast remarkable resilience and sustainability features, and older constructions lag.

SCENARIO 2

Self-Sustaining Highways (The End to Infrastructure Bills?)

Bioengineering introduces advanced materials for highways and bridges that incorporate microorganisms, which produce substances to naturally repair damages, thereby enhancing durability and slashing maintenance expenses. These innovations adapt to fluctuating environmental conditions, offering better resistance against extreme weather patterns and contributing to infrastructure longevity. Some highway infrastructures mend themselves and reduce CO_2 levels, while bridges utilize embedded sensors for ongoing health monitoring, ensuring safety and operational efficiency.

UNCERTAINTIES

Securing Agricultural Infrastructure

Bioengineering addresses the global food security challenge by revolutionizing how and where we grow our food. Improved crop yields enable food cultivation in diverse and previously inhospitable locations. Bioengineering also offers solutions to the most pressing agricultural challenges, such as developing famine and disease-resistant crops, engineering drought-tolerant plants that thrive on less water, and reducing reliance on chemical fertilizers and pesticides by creating all-natural pest resistances. Crops now withstand shifting weather patterns, while soil health is improved.

SCENARIO 1

World War Food

Wealthier nations, foreseeing the vulnerabilities of relying on traditional agriculture, heavily invested in synthetic biology and food synthesis technologies to produce engineered foods customized for nutritional content.

This shift has created a new divide in the global economy, with disparities in food production capabilities. Agrarian countries, dependent on their exports of traditional crops, face widespread unemployment and social unrest. They retaliate through cyber sabotage and proxy conflicts, attempting to disrupt their wealthier counterparts' engineered food supply chains.

SCENARIO 2

Community-Focused Food

Genetic modification and environmental adaptation have revolutionized agriculture. Crops flourish in deserts and on urban rooftops, making food production sustainable and accessible. The urban heat island effect is reduced, and fresh produce and cultured proteins are available at local shops. Suburban and rural communities have embraced cooperative farms growing bioengineered crops resistant to various adversities, enhancing local biodiversity and fostering shared responsibilities and benefits. Commercial farming has shifted toward sustainability, with genetically engineered crops achieving faster growth and higher yields, leading to reduced land use, shorter supply chains, and less reliance on imports. Food is grown closer to where it is consumed, leveraging advanced technologies to create a resilient, efficient, and eco-friendly food system.

OPPORTUNITIES & THREATS

THREATS

1 Genetic Privacy and Discrimination Risks
A rise in bioengineering raises concerns over genetic data privacy. There's a risk that insurers, employers, or third parties could misuse individuals' genetic data, leading to new forms of discrimination.

2 Automation In Employment
Integrating bioengineering in various industries may lead to significant job displacement. Traditional agriculture, construction, and health care roles could be transformed or made obsolete by automated processes.

3 Geopolitical Conflict
The strategic advantage gained through bioengineering capabilities could become a source of global tension. Leading nations may exert influence over others, leading to new forms of dependency and inequalities.

OPPORTUNITIES

1 Adapting to the Never-Retiring Workforce
The increase in life expectancy will drive shifting career dynamics, allowing businesses to develop new career paths, flexible working conditions, and retirement plans that accommodate an aging but active workforce.

2 Bridging the Gap in Health Access
Advancements in bioengineering offer unprecedented opportunities to address health inequities globally through more cost-effective production of pharmaceuticals.

3 Improved Food Access
Synthetic biology revolutionizes global food strategy by boosting crop resilience, enhancing nutrition, producing sustainable ingredients, developing alternative proteins, and reducing waste, leading to more resilient food systems.

STRATEGIC QUESTIONS

1

How can synthetic biology be used to solve previously unsolvable problems in your product R&D pipeline?

2

What impacts do you anticipate synthetic biology will have on your supply chain and procurement strategies?

3

How will your customers and the market respond to products or services developed through synthetic biology?

4

What skills and talent do you need to leverage synthetic biology in your business effectively, and how do you plan to acquire them?

5

How do you plan to manage intellectual property rights and protect innovations in the field of synthetic biology, and what challenges do you foresee in this area?

RETURN TO UNCERTAINTIES

03

How will countries and businesses commit to decarbonization?

UNCERTAINTIES

How will countries and businesses commit to decarbonization?

Blue Economy

GET THE DETAILS

An Expanded Environmental Support Ecosystem

GET THE DETAILS

Inclusive, Multifaceted Environmental Protection

GET THE DETAILS

Sustainable Growth and Innovation

Exploitation and Environmental Degradation

Grid Optimization

Environmental Efforts Stagnate

Holistic Benefits Are Realized

Over-regulation and Complexity Dominate

UNCERTAINTIES

Blue Economy

The blue economy, which promotes the sustainable use of ocean resources, plays an increasingly important role in countries' sustainability efforts by harnessing the ocean's economic growth while ensuring marine environmental health. This approach includes sustainable fisheries, renewable marine energy, and eco-friendly tourism, all aimed at preserving ocean ecosystems and promoting economic resilience.

SCENARIO 1

Sustainable Growth and Innovation

Marine technology breakthroughs vastly improve sustainable fishing, ocean-based renewable energy efficiency (like wave and tidal power), and ocean cleanup efforts, significantly reducing marine pollution.

Concurrently, robust international agreements are instrumental in the effective management of marine resources. These agreements introduce strict regulations to prevent overfishing and protect marine habitats from destruction. Because of these combined efforts, the health of the marine ecosystem improves.

SCENARIO 2

Exploitation and Environmental Degradation

Inadequate global governance fuels overfishing, unregulated marine development, and pollution, drastically diminishing ocean resources.

Wealthier nations disproportionately deplete these resources, leaving smaller coastal communities to bear the brunt of environmental harm and resource scarcity.

Ignoring sustainable methods leads to a sharp decline in biodiversity, undermining the blue economy's growth, affecting worldwide food security, and disrupting climate balance. These effects are most acutely felt by small coastal communities reliant on the ocean for survival.

UNCERTAINTIES

An Expanded Environmental Support Ecosystem

Countries expand their environmental efforts beyond a narrow focus on renewable energy to include broader ecosystem support. This involves enhancing infrastructure such as power grids and EV charging networks, implementing environmental, social, and governance (ESG) policies, and bringing greater transparency to carbon trading schemes. The aim is to take a more holistic approach to sustaining healthy ecosystems while still continuing the transition toward clean energy.

SCENARIO 1

Grid Optimization

Energy grids have been upgraded through deployment of advanced energy storage systems, such as large-scale batteries and pumped hydro facilities. We now store excess renewable energy. There is widespread adoption of highly efficient electric heat pumps for heating and cooling to reduce energy use and curb emissions. New ESG policies include transparency for CO_2 trading schemes.

Businesses supporting optimized grid initiatives benefit from reduced energy costs thanks to improved stability and more energy-efficient technologies. These businesses also tap into emerging renewable energy markets, creating new revenue streams. Those leading the transition to sustainable power grids have a first-mover advantage.

SCENARIO 2

Environmental Efforts Stagnate

Persistent power outages and insufficient electric vehicle infrastructure disrupt economic activities, causing a dip in productivity and risking job losses. Since ESG regulations vary across regions, compliance is difficult. This leads to higher operational expenses and hampered economic expansion. A lack of transparency in carbon trading markets breeds investor skepticism, obstructing the development of green finance.

UNCERTAINTIES

Inclusive, Multifaceted Environmental Protection

The concept of environmental protection has evolved to become more inclusive. Countries and businesses now recognize that it encompasses efforts to mitigate climate change and initiatives for biodiversity conservation and the promotion of humane working conditions. This broader approach integrates ecological sustainability with social responsibility, reflecting a more holistic understanding of our interconnected world.

SCENARIO 1

Holistic Benefits Are Realized

Nations prioritize the conservation of diverse ecosystems, leading to increased ecotourism, research opportunities, and sustainable resource management. Responding to labor group advocacy, businesses adopt fair labor practices, including raising wages and prioritizing safer work environments.

Companies embrace comprehensive sustainability strategies that integrate ecological, social, and economic considerations, leading to significant reductions in resource waste and improved financial resilience. These strategies are effective because they strike a balance between environmental consciousness and business viability, aligning with consumer preferences for environmentally responsible goods and services.

SCENARIO 2

Over-regulation and Complexity Dominate

Expanded environmental protection efforts bring complex and often competing regulations to the forefront, and governments have to wrestle with noncompliance and enforcement challenges. Businesses face exorbitant costs navigating this convoluted regulatory landscape, stifling innovation and hindering economic growth. The high cost of transitioning to environmentally friendly legislation poses barriers to entry for smaller businesses, reducing market competition.

In striving to meet a multitude of environmental goals, overemphasis on specific areas like biodiversity conservation diverts finite resources from urgent climate mitigation needs, impeding overall sustainability progress.

OPPORTUNITIES & THREATS

THREATS

1 Compliance Complexity
Diverse and changing ESG regulations across regions can complicate compliance efforts, increasing operational costs and reducing competitiveness.

2 Technological Obsolescence
Rapid advancements in energy technologies could render existing products and services obsolete, posing a threat to businesses unable to innovate quickly.

3 Implementation Costs
The costs associated with adopting comprehensive sustainability strategies could be significant, particularly for small and medium-sized enterprises (SMEs).

OPPORTUNITIES

1 Short-Term Gains
Businesses prioritizing short-term economic gains over sustainability may benefit from lower compliance and operational costs in the short term but could find themselves ill-prepared over the mid-term as new technologies and regulations begin to scale.

2 New Revenue Streams
Companies in the energy storage, electric heat pumps, and renewable energy sectors could tap into new revenue streams as their technologies and services become increasingly in demand.

3 Comprehensive Sustainability
Companies that adopt and integrate broad sustainability strategies can appeal to a wider customer base, reduce waste, and improve operational efficiencies.

STRATEGIC QUESTIONS

1

How is your business leveraging technological advancements in marine technology to promote sustainable growth within the blue economy?

2

What strategies are in place to adapt to and comply with international marine resource management agreements, such as in your supply chain practices?

3

How is your business preparing to align with new ESG policies, and what investments are being made to upgrade or support the infrastructure for renewable energy and grid optimization?

4

How is your business diversifying its operations or supply chains to ensure resilience and sustained growth?

5

What measures are in place to navigate the complexity of expanded environmental regulations without stifling innovation or economic performance?

RETURN TO UNCERTAINTIES

04

How will humans prioritize their work environments in the future, and what will these preferred workplaces look like?

UNCERTAINTIES

How will humans prioritize their work environments in the future, and what will these preferred workplaces look like?

Work Is Task-Dependent

GET THE DETAILS

Enabled by Smart Workspaces and AI Agents

GET THE DETAILS

Purpose-Driven Locations

GET THE DETAILS

Decentralized Work Communities

Reskilling for Task-Based Work

Smart Workspaces Empower Talent

AI Agents Manage Logistics

Personalized Coworking Ecosystems

Division in Urban Areas

UNCERTAINTIES

Work Is Task-Dependent

Companies emphasize skill-focused tasks over traditional role-based assignments. This approach opens up opportunities for both fixed-location and remote workers, breaking down previous barriers in talent pools. Consequently, employees have the flexibility to work from home or community-based locations.

SCENARIO 1

Decentralized Work Communities

The social elements and team structures of traditional offices diminish in importance. Without defined roles anchoring them together, employees perform their individual tasks remotely.

Workers split time between truly remote work and convening in smaller satellite workspaces when they want a sense of community. Employees enjoy the flexibility to simultaneously hold multiple "careers," contributing varied tasks to an ecosystem of employers rather than being siloed at any single organization.

SCENARIO 2

Reskilling for Task-Based Work

Ensuring the right skills for each job is a priority. Sensitive to the high search costs for new talent, companies are interested in retaining and training existing employees to meet evolving task needs. Traditional offices are nimble learning centers focused on immersive training for current staff.

This cultivated talent pipeline of cross-functional employees, versed in specific on-demand abilities, replaces siloed departments. Companies equip their workforce with precise capabilities rather than seeking elusive candidate fits.

UNCERTAINTIES

Enabled by Smart Workspaces and AI Agents

Workflows are enabled by fluid, personalized environments that empower productivity with human and artificial partners working in concert. People are free to perform, augmented by supportive spaces that travel with them.

SCENARIO 1

Smart Workspaces Empower Talent

Offices function as intelligent computing zones. Spatial computing and natural language processing enable embodied interaction. Employees' tasks and projects surface on walls and tables as they enter a room. Workers can literally get a grasp on their work by manipulating 3D projections by hand. Voice commands replace typing for nimble modification.

Employees gain sensory proximity to their work. Previously abstract digital files are now tangible in augmented environments that both feel familiar and unleash workspace innovation.

SCENARIO 2

AI Agents Manage Logistics

Specialized AI agents handle distinct tasks. A product manager AI agent could aid market analysis, prioritize features, and develop business cases. Meanwhile, a developer agent would focus on automating code generation and detecting bugs.

Each person's AI agent coordinates to remove logistical burdens. Christina's assistant tracks that she prefers morning meetings. Jeff's assistant knows he favors early afternoons. By sharing insights into their humans' constraints, the assistants identify 11 a.m. as the optimal meeting time. Because the assistants dynamically adjust activities based on their human's context, they enable new flexibility: Workers can perform efficiently wherever they happen to be.

UNCERTAINTIES

Purpose-Driven Locations

Workers want transparency and a seat at the table to make company decisions. Labor unions and employees continue to push for greater autonomy and new benefit packages and locations. Companies join together to offer a complex of potential work environments, creating stability in some urban regions.

SCENARIO 1

Personalized Coworking Ecosystems

Employees have access to coworking ecosystems that cater to their lifestyles. For health buffs, wellness hubs provide gyms, cold plunges, and saunas. Parents join family-friendly sites with childcare and nursing spaces. Rather than isolated offices, companies cluster in amenity-rich locales to give workers choices.

Workers evaluate these full experience packages when considering job opportunities. Companies differentiate with tailored sites while still coming together in broader mixed-use developments. Competing businesses may not share ecosystems, but complementary industries do, recognizing the potential for expanded talent recruitment and retention.

SCENARIO 2

Division in Urban Areas

The urban centers of cities are becoming patchworks of utilitarian spaces that lack the vibrancy and interconnectedness of traditional urban life. As offices emptied out due to employee cynicism, businesses turned their properties into lab spaces, vertical farms, and storage. Socio-economic divides are deep, as these spaces do not address communal needs, only corporate interests. Once vibrant downtowns focus on efficiency and production versus community connection. Manufacturers are using the empty spaces to fill warehouses and production sites closer to their consumers. Malls and other shopping facilities that moved out of downtown now compete with these manufacturing centers.

OPPORTUNITIES & THREATS

THREATS

1 Ethical Challenges with AI Integration
Integrating AI agents into the workforce introduces cultural and ethical challenges, including dependency on technology, potential job displacement concerns, and ethical considerations around AI decision-making.

2 Overdependence on Technology
Heavy reliance on smart workspaces and AI for operational efficiency could lead to overdependence on technology, making companies vulnerable to tech failures, outages, or obsolescence.

3 Fraud Risk
As decentralized work scales alongside increasingly sophisticated AI, various forms of deepfakes could present a security risk to remote working environments, necessitating businesses to improve their cybersecurity preparedness.

OPPORTUNITIES

1 Talent Ecosystem Development
Companies and industries can develop talent ecosystems that foster cross-pollination of skills and ideas by creating networks of complementary businesses and coworking spaces that enhance talent satisfaction and retention.

2 Urban Redevelopment and Repurposing
Municipalities and businesses will need advice on repurposing urban spaces that have lost their traditional vibrancy due to shifts in work patterns.

3 Purpose-Driven Workspace Solutions
Companies may create purpose-driven locations and co-working ecosystems that align with their employees' values and lifestyle preferences. This could involve strategic planning for the use of corporate real estate to support community engagement, wellness, and collaboration.

STRATEGIC QUESTIONS

1

How can we develop a continuous learning and development ecosystem to ensure our workforce remains adaptable and skilled for future tasks?

2

In what ways can we leverage smart workspaces and AI agents to enhance productivity without compromising security, privacy, and employee well-being?

3

What do we need to reevaluate or adjust in order to remain competitive in attracting and retaining top talent as the workspace evolves?

4

How can we leverage data and analytics to improve remote work productivity and employee engagement while respecting privacy and autonomy?

5

**How can we use new and emerging technologies to foster innovation and creativity in a predominantly remote or hybrid workforce?**

RETURN TO UNCERTAINTIES

05

In the context of increasing protectionism and geopolitical tensions, what is the future of the global chip manufacturing industry?

UNCERTAINTIES

In the context of increasing protectionism and geopolitical tensions, what is the future of the global chip manufacturing industry?

Chip Imports and Exports Are Increasingly Restricted

GET THE DETAILS

Protectionist Policies Result in a Skills Gap

GET THE DETAILS

The Cost of Data Centers Rise

GET THE DETAILS

The US Dominates

China Rallies

In-House Production and Training Ramp Up

Open Borders for Chip Industry Growth

Tech Companies as New Energy Providers

The End User Pays

UNCERTAINTIES

Chip Imports and Exports Are Increasingly Restricted

The industry continues its pivot toward strategic autonomy. Defensively, the US is onshoring chip production to prevent supply chain disruptions like those during the Covid semiconductor shortage. Offensively, the US is strategically preventing exports to get a leg up in the AI race against China. Meanwhile, independent companies, like OpenAI, want to create new types of chips that won't run afoul of government regulations.

SCENARIO 1

The US Dominates

The US tightens enforcement of chip exports to prevent adversaries from attaining US chips and manufacturing equipment. US allies are required to do the same. Technologies like geotracking prevent leaks in export controls, thereby more effectively curbing US technologies from getting to China and Russia. This challenges those countries' reliance on foreign chips, pressuring their big tech to innovate with less sophisticated resources.

Since China is a major player in the consumer electronics market, the restrictions lead to higher prices and limited availability of various consumer goods worldwide.

SCENARIO 2

China Rallies

US-led export controls do not prevent China and other adversaries from acquiring powerful chips from companies like Nvidia. Black markets emerge for such chips, and IP espionage efforts ramp up. With these powerful chips, China's AI rivals US AI companies in capabilities. There is a bifurcation of "Eastern AI" and "Western AI."

China also continues to dominate global legacy chip production. Legacy chips underpin everything from microwaves to military weapons systems. China boxes out foreign competitors through dumping, rendering the US dependent on China, at least for legacy chips.

UNCERTAINTIES

Protectionist Policies Result in a Skills Gap

The expertise required for chip design and production, previously outsourced affordably, is now lacking domestically. As a result, manufacturing chips domestically has become a costly endeavor. This has sparked intense competition among companies to attract and acquire talent specialized in chip design and manufacturing.

SCENARIO 1

In-House Production and Training Ramp Up

Semiconductor companies are bringing chip production in-house and cultivating essential skills internally. They also in-source skills training by reaching out to high school students, offering a direct path into the burgeoning US chip industry. This new model positions the semiconductor sector as a realm of new blue-collar workers. By providing in-house training and certification, these companies offer young talent a debt-free alternative to college education, enabling them to start earning immediately while learning specialized skills.

SCENARIO 2

Open Borders for Chip Industry Growth

Progress in opening new fabrication plants, funded by the US Chips Act, has been slower than anticipated. The fabs' hosts, including cities in Texas, Ohio, and Florida, worry about becoming modern equivalents of Detroit—where initial high investments won't yield long-term benefits.

States traditionally resistant to open immigration policies are shifting their stance, and the US is responding with expedited visas for skilled workers, particularly from Taiwan, leading to a notable brain drain in the island nation and increased tensions with China.

UNCERTAINTIES

The Cost of Data Centers Rise

As AI-driven workloads intensify, the operational costs of data centers are escalating. The increased demand for processing power and energy to support complex AI tasks significantly drives up the expenses associated with maintaining and running these facilities.

SCENARIO 1

Tech Companies as New Energy Providers

Tech companies are venturing into producing alternative, cost-effective energy sources like small modular reactors and geothermal power. This move is not just about affordability; it represents a leap in overcoming long-standing negative perceptions of nuclear energy and its historical barriers of high costs and lengthy construction times.

The implications are profound, and not just for the energy sector: Apartment buildings will be powered, cooled, and lit efficiently by Amazon, and entire neighborhoods receive clean, cost-effective energy from Google or Microsoft.

SCENARIO 2

The End User Pays

Data center efficiency advancements have reached a plateau, compelling the industry to focus on expansion to meet increasing workload demands.

Providers can try to stay in densely populated areas that offer skilled labor availability and robust fiber networks, but they'll have to deal with increasing restrictions amid concerns that data centers exacerbate energy shortages. Or they could venture into less ideal locations lacking infrastructure and requiring substantial capital investment. Either option presents an increased cost of digital services for consumers and a significant ripple effect across the economy.

OPPORTUNITIES & THREATS

THREATS

1 Big tech gets bolder
Utilities could become disintermediated by tech companies, who find a competitive advantage in bundling energy with other services.

2 Regulatory disruption
Changes in trade policies and regulations in key markets could affect access to critical chip technologies and materials.

3 Tech transfer
Intellectual property and sensitive technology become entangled in technology transfer regulations, especially in countries involved in geopolitical tensions.

OPPORTUNITIES

1 Cultivate partner and supplier relationships
Businesses will need to develop new partners, manufacturers, and markets so they have first mover advantage if geopolitical tensions rise unchecked, impacting access to key components and markets.

2 Get local
Companies may Invest in local or regional production capabilities to reduce dependence on global markets, increasing customization capabilities and time to market.

3 Fund alternatives
Technology firms must invest more in research and development to create more advanced or alternative chip technologies that address the emerging challenges.

STRATEGIC QUESTIONS

1

How will geopolitical tensions affect the cost of chips, and how can you mitigate these cost increases?

What financial cushions can be put in place to absorb potential shocks?

2

Do you have a robust crisis management plan that includes scenarios involving escalated geopolitical tensions affecting chip supply?

3

How must you enhance your cybersecurity measures to protect against potential threats exacerbated by geopolitical tensions, especially in critical infrastructure related to chip manufacturing and distribution?

4

How do geopolitical tensions affect your commitment to environmental sustainability and ethical sourcing, especially concerning rare materials used in chip production?

5

Considering the current and potential future geopolitical landscape, how should you adjust our long-term strategic positioning to ensure sustainability and growth?

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ARTIFICIAL INTELLIGENCE

Future Today
Institute

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YOUR GUIDE TO THE FUTURE OF AI

For two decades, our commitment at Future Today Institute to understanding and leveraging artificial intelligence has been unwavering—even as general excitement about AI has wavered considerably. We've watched interest ebb and flow across industries, among executive leadership and boards of directors, and with investors, legislators, and academia.

Today, we're at a crucial inflection point in AI's developmental journey. This moment isn't marked by a single technological breakthrough but rather by a development that at first may seem less intuitive. What changed in the past year is our perception of what AI is and how it will change everyday life. AI models are now accessible to consumers and businesses alike, so their value can be immediately understood. What's followed: investment, new partnerships, and the grand expansion of value networks.

This rapid escalation in activity has left leaders feeling caught off guard, prompting an urgent need for strategic decision-making. In our conversations with clients and partners, a common theme has emerged: Leaders, understandably concerned about missing out on the next wave of innovation, need clarity about a complex area of technology that will continue to evolve for many years to come.

Recognizing this, we've reimagined our approach for the AI section of our 2024 Tech Trends report. By actively listening to leaders and experts in our network, we've curated the most common questions we're hearing from our clients and grouped our AI trends accordingly. Our goal is to guide leaders through a thoughtful exploration of these questions, enabling a deeper understanding of the implications.

While we don't claim to hold all the answers—every organization's journey with AI will be somewhat unique—what we do offer is a foundation of extensive research and insightful, strategic analysis. You will encounter questions that mirror your own, as well as those you may not have considered but will likely confront in the coming year. Our aim is to equip you with the insights necessary to navigate the upcoming impacts on your organization.

We are confident that this report will serve as an invaluable tool for leaders looking to identify strategic opportunities, achieve competitive advantages, and enhance organizational resilience in the foreseeable future.

Welcome to your guide on the future of AI.

Amy Webb
Chief Executive Officer

Sam Jordan
Manager and Advanced Computing Practice Lead

TOP HEADLINES

This year, the AI landscape could undergo a significant consolidation. Strategic investments, groundbreaking innovations, and regulatory maneuvers will further empower a select group of power brokers, intensifying the competitive dynamics and shaping the trajectory of global AI dominance.

01 OpenAI Seeks $7 Trillion Investment

OpenAI's Sam Altman wants to revamp the semiconductor sector with trillions in investment, targeting global chip capacity to boost AI growth, engaging with investors like the United Arab Emirates.

02 Mainstream Multimodality

For the first time, the public can interact with advanced multimodal AI models capable of understanding and generating various media types, including images and videos. This innovation is akin to human learning processes, enabling AI to learn from visual and auditory information, not just text—just like us.

03 Nvidia GPUs in High Demand for AI Training

The rush to acquire Nvidia's powerful GPUs for AI model training has intensified, as everyone from tech giants to startups seeks the computational horsepower these units offer for advanced machine learning tasks.

04 Open-Source AI Uprising

Meta sparked an open-source large language model movement by releasing the weights for LLaMA, enabling researchers to freely build off the model, fine-tune it, and create customized versions.

05 US Tightens Grip on AI

The US intensifies its stance on AI by restricting access to crucial enabling technologies like semiconductors. In a strategic move, the US also pressures allies to implement similar restrictions against China and Russia.

06 EU AI Act Sets New Global Standard

The EU introduces the first-ever comprehensive AI regulation and a European AI Office, aiming to ensure safety and respect for fundamental rights, while encouraging innovation and investment in AI technologies across Europe. Yet, concerns arise about stifling innovation and the high costs for businesses to comply.

STATE OF PLAY

AI embeds into everything, transforming how we interface with computers while researchers work to make AI more capable and efficient. This sprint toward progress unfolds amid rising geopolitical tensions, as dominance of these strategic technologies reshapes global power dynamics.

The past year marked a watershed moment for artificial intelligence. Central to this transformation are the leaps in large language models (LLMs) and their practical applications, which have not only advanced the frontiers of AI but have also catalyzed a broader integration of AI technologies into everyday life. AI promises revolutionary improvements in health care and life sciences: Now that we've cracked the code on protein structures, an unimaginable number of new therapeutics are on the horizon, along with alternatives to address climate change. In the coming year, AI's reach will extend to people, pets, and objects alike, paving the way for a very near-future in which digital assistants, automated systems, and spatial awareness are seamless, ubiquitous, and invisible. In parallel, the advancements in robotics, both hard and soft, are pushing the boundaries of automation and human-machine interaction.

At the same time, AI's energy demands pose a paradox, offering climate solutions but also contributing to carbon emissions, a concern in energy-constrained areas. The persistent talent gap in AI, particularly in data science, limits its application in critical sectors like agriculture and health care. Political engagement with AI is growing, which is good, but the end result has been a slew of competing policies. Regulatory compliance and enforcement remains a challenge, since depending on the country's position, they promise to both accelerate and curtail the deployment of AI systems. The unequal distribution of AI advancements risks deepening global inequalities, with the global south facing significant disadvantages. Amid all these developments is the persistent geopolitical tensions between China and the West.

For many, generative AI (genAI) is the first entry point into this new reality, which explains the explosive growth we've seen in the past year. Our analysis reveals a

STATE OF PLAY

surge in experimentation with genAI tools across various sectors, indicating a transformative shift toward embracing AI's potential to innovate and streamline operations. This widespread interest in genAI spans a broad spectrum of stakeholders, from business leaders to frontline workers, highlighting just how pervasive the first generation of tools has become.

But here's the thing: GenAI isn't all of AI. Often, when people talk about "AI" what they really mean is "automation." Artificial intelligence is an umbrella term that encompasses many different techniques, models, and frameworks that make up the field. AI's aim is to create intelligent machines that can sense, reason, act, and adapt like humans do, or in ways that go beyond our capabilities. Today, cars can park themselves, while emerging platforms are capable of having seemingly natural conversations. Now, AI is evolving to have beyond-human capabilities. It has invented new drugs, predicted the real-time movement of wildfires, and autonomously designed machine parts.

Developing AI requires extraordinary resources, which is why consolidation among the tech giants is tightening. The biggest names in AI––OpenAI, Deep-Mind, Anthropic––are increasingly hitched to the world's biggest hyperscalers and cloud providers (Microsoft, Google, Amazon). Venture capital and private equity are still flooding into startups and mature companies alike, and now, sovereign wealth funds have a seat at the table.

AI is magical, but it isn't magic. As long as expectations are tempered, this should be an era of significant innovation, experimentation, and growth, especially as AI propels growth in other areas of science and technology. We are cautiously optimistic about what's on the horizon.

KEY EVENTS

JANUARY 12, 2023

AI Breakthrough in Lung Cancer Detection

A joint effort by MIT and Mass General Hospital yields a significant advancement in lung cancer prognosis with the creation of a deep-learning model that assesses lung cancer risk from CT scans, potentially enhancing early detection and saving numerous lives.

JANUARY 26, 2023

High-Fidelity Music from Text

Google Research's MusicLM introduces a transformative approach to generating detailed music from text descriptions, achieving unprecedented audio quality and text adherence in the field.

FEBRUARY 6, 2023

Google Unveils Bard

Google introduces Bard, an innovative AI chatbot powered by its language model LaMDA, as a response to ChatGPT.

FEBRUARY 7, 2023

Bing Adopts ChatGPT

Microsoft revolutionizes its Bing search engine and Edge browser with the integration of OpenAI technology.

FEBRUARY 21, 2023

AWS and Hugging Face Collaboration

AWS teams up with Hugging Face to streamline AI projects on Amazon's cloud, simplifying the deployment of AI applications.

FEBRUARY 21, 2023

Real Fusion's Photographic Breakthrough

Oxford researchers showcase Real Fusion, a cutting-edge AI that can reconstruct a complete 360-degree photographic model from just one image.

FEBRUARY 24, 2023

Meta introduces LLaMa

The compact yet advanced 65-billion parameter language model is open-sourced and free for research and commercial use.

MARCH 1, 2023

OpenAI Expands Developer Tools

OpenAI launches ChatGPT and Whisper APIs, providing developers with advanced language processing and speech-to-text capabilities beyond basic chat functions.

MARCH 14, 2023

Google Introduces AI in Workspace

Google's launch of assistive AI features in Workspace started with AI-powered writing tools in Docs and Gmail for trusted testers.

KEY EVENTS

MARCH 21, 2023

Adobe Unveils Firefly

This new generative AI suite is designed to help users at all skill levels create high-quality images and text effects.

MARCH 28, 2023

Khan Academy Launches Khanmigo

Khan Academy launch of the Khanmigo AI platform integrates virtual bots as counselors, curriculum designers, and teaching assistants.

AUGUST 15, 2023

Google Launches Search Generative Experience

Google introduces genAI into search queries, automatically generating summaries.

SEPTEMBER 21, 2023

Microsoft Unveils Co-pilots

Microsoft's AI-powered 365 Copilot and GitHub's CopilotX offers enhanced assistance by integrating web context, work data, and real-time PC activities, prioritizing privacy and security.

SEPTEMBER 21, 2023

YouTube Debuts AI Editing App

The new app, YouTube Create, makes it easy to trim videos, slow down the pace, or add audio.

OCTOBER 25, 2023

Amazon Introduces AI Image Generation

Amazon rollout of AI-powered image generation capabilities through Amazon Ads in beta aims to enhance ad experiences by enabling brands to create lifestyle imagery that boosts ad performance.

NOVEMBER 4, 2023

Elon Musk's xAI Debuts Grok

Inspired by the "Hitchhiker's Guide to the Galaxy," Grok answers questions with wit and provides real-time world knowledge via the X platform, distinguishing itself by addressing inquiries often declined by other AIs.

NOVEMBER 14, 2023

Google Announces AI Genesis

AI Genesis features the Gemini large language model in three sizes: Gemini Ultra for extensive capabilities, Gemini Pro for broad task applications, and Gemini Nano optimized for specific tasks and mobile use.

NOVEMBER 17-22, 2023

OpenAI's Turbulent Week

After a tumultuous five days marked by his ouster and subsequent reinstatement, Sam Altman resumes his role as CEO of OpenAI, buoyed by a concerted effort from allies, employees, and investors.

KEY EVENTS

NOVEMBER 21, 2023

StabilityAI Introduces Stable Video Diffusion

StabilityAI's inaugural foundation model for generative video builds on the technology of its image model, Stable Diffusion.

NOVEMBER 28, 2023

Pika Debuts AI Video Editing App

The app includes a new suite of videography tools with a generative AI model that edits videos in diverse styles such as "3D animation," "anime," and "cinematic."

NOVEMBER 29, 2023

DeepMind Predicts Novel Material Structures

Google DeepMind's researchers have leveraged AI to accurately predict the structures of more than 2 million new materials, offering significant implications for renewable energy and computing sectors.

DECEMBER 5, 2023

AI Alliance for Responsible Innovation Forms

The AI Alliance for Responsible Innovation, including IBM, Meta, and 50 other organizations, launches as a global consortium aimed at promoting open, safe, and responsible AI development and adoption.

DECEMBER 6, 2023

Google's Gemini Surpasses GPT-4

Google's next-generation AI model outperformance of OpenAI's GPT-4 set a new standard in AI capabilities.

DECEMBER 9, 2023

EU Finalizes AI Act

The European Union achieved a landmark agreement with the Artificial Intelligence Act, introducing binding rules and standards for developing AI more responsibly.

DECEMBER 13, 2023

Axel Springer Partners with OpenAI

The German media titan's partnership lets OpenAI use Politico and Business Insider articles for AI training, while those news platforms get to employ ChatGPT for summarizing news, marking a significant yet controversial collaboration in the news industry's quest for innovation and survival.

DECEMBER 14, 2023

DeepMind's FunSearch Breaks Boundaries

The tool has successfully solved complex issues, proving AI's ability to surpass the limitations of its training data in large language models (LLMs).

DECEMBER 14, 2023

DeepMind Solves the Unsolvable with AI

DeepMind's use of an LLM to crack an "unsolvable" math problem marks a historic achievement, as detailed in Nature, showcasing the model's capacity to uncover new, verifiable knowledge on a longstanding scientific challenge.

LIKELY NEAR TERM DEVELOPMENTS

GENERAL	ENTERPRISE	AUTOMATION	REGULATION AND GEOPOLITICS
Commoditization of General Purpose Models In the near future, expect the commoditization of general purpose models. LLMs are becoming widely accessible and integral to app development. As these models become ubiquitous and cost-effective, akin to cloud services, their adoption will standardize across industries, diminishing their role as a competitive differentiator.	**Talent Shift in AI Industry** Expect a significant talent crunch as top innovators depart major tech giants like Google, OpenAI, and Meta to launch their own ventures, ranging from conversational agents to AI-first biotech firms, signaling a broad diversification and specialization within the AI sector.	**AI Assistants Transform Coding Landscape** AI coding assistants, such as GitHub's Copilot and Meta's Code Llama, are transforming software development with advanced autocomplete functions and innovative debugging tools, offering both premium and free solutions to enhance coding efficiency and creativity. Expect to see more improvements to these tools and more tools to launch in this space.	**US Strategy on AI and China Relations** The US is expected to intensify efforts to get allies to limit their collaborations with China in AI development, following President Biden's enhanced export restrictions on semiconductors. With the Netherlands aligning with US requests, further demands on allies to adopt similar stances aim to curb China's AI advancements.
Large Reasoning Model Vertically integrated solutions will garner a higher transactional value. Some companies will win by providing "a refined/value-added LLM product" to the end consumer and meeting the customer in desired distribution channels, such as LLMs for health care, legal, finance, and architecture.	**Consolidation in 2024** Consolidation will persist this year, building on moves like Microsoft's 2023 increased investment in OpenAI for Bing, aimed at capturing market share from Google search. Similar strategies by major tech companies are anticipated throughout 2024.	**AI Integration in Health Care and Life Sciences** Generative AI will lead to breakthroughs in proteins, antibodies, and drugs. Specialized models will continue to accelerate discovery in biology and chemistry, sparking more practical applications and boosting investment.	**Europe Begins Regulating AI** The European Commission will open its European AI Office, which will oversee the development and use of safe artificial intelligence (within Europe, at least) and assist with the implementation of the AI Act. The office will enforce general purpose AI rules, monitor compliance, and attempt to become a hub for international cooperation on AI governance.
Adoption of Natural Language Interfaces The evolution toward natural language interfaces will soon diminish the reliance on traditional graphic user interfaces. This shift will enable more intuitive interactions with computers, using everyday language. This transition may also influence device form factors, potentially leading to an increase in wearables and the development of AI-specific devices and operating systems centered around LLMs.	**Increased Enterprise Adoption of AI** The current macroeconomic environment is driving leaders to view AI as essential for growth, anticipating increased enterprise adoption despite the potential for making some job categories obsolete.		**Challenges in US Chip Manufacturing Expansion** The US moves to onshore chip fabrication will experience growing pains associated with higher labor costs compared to Taiwan. This shift may lead to increased expenses in constructing fabs and producing domestically made chips, surpassing initial estimates outlined in the CHIPS Act.

WHY ARTIFICIAL INTELLIGENCE TRENDS MATTER TO YOUR ORGANIZATION

Business Impacts

Future Today Institute believes AI is a force multiplier on technological progress because it is an enabler of other technologies and powers the evolution of business, government, and society. But new large language model capabilities deeply concern some in professional and creative services. Models can now reason about concepts in text, not just perform pattern matching. They display forms of common sense and analogy—tasks once seen as uniquely human. And they apply these reasoning abilities across modalities—text, image, video, and more. Most alarming to some is that models seem to engage in recursive self-improvement when given the right training. They don't just learn a static set of parameters. They learn how to learn better, becoming moving targets.

Since publishing our first Tech Trends report 17 years ago, we have included and expanded our coverage on artificial intelligence. What began as several pages of insights is now a dedicated, stand-alone report with more than 100 trends to monitor. AI is already transforming most economic sectors, but we anticipate deeper impacts this year across insurance, finance, entertainment, health care, biotechnology, and cloud computing.

Global Tech Rivalry

The race for AI supremacy is intensifying geopolitical tensions, notably between the US and China. Businesses must navigate a landscape where technology and national security are increasingly intertwined, affecting international supply chains, market access, and regulatory compliance. Companies specializing in AI and related technologies might face stricter export controls, requiring them to adjust strategies for product development and global expansion.

Supply Chain Diversification and Onshoring

As tensions escalate, particularly in the semiconductor industry, businesses will need to diversify their supply chains to mitigate risks. The bifurcation in the AI chip market might compel companies to innovate independently or bring supply chains in-house, potentially leading to increased costs.

WHY ARTIFICIAL INTELLIGENCE TRENDS MATTER TO YOUR ORGANIZATION

Defense Sector Innovation

Updated Department of Defense policies on autonomous weapons and the use of AI in military strategies signal growing opportunities for businesses in the defense sector. Companies developing AI technologies could find new applications in warfare, surveillance, and security, but also face ethical and regulatory scrutiny.

Strategic International Collaborations

Countries like China and the UAE are heavily investing in becoming global AI leaders, which presents both opportunities and challenges for international business collaborations. Companies might need to align with national AI strategies to enter or expand in these markets, while also considering the implications of technology transfer and data security regulations.

Strategic Talent Acquisition

Companies must innovate in talent acquisition and retention strategies to compete for scarce AI expertise, particularly against tech giants. This may include offering competitive salaries, benefits, and unique work environments, as well as investing in employee development and internal AI training programs to build talent in-house.

Custom, Fit-for-Purpose LLMs

Organizations that opt for custom AI models over general-purpose ones can achieve greater alignment with specific business objectives. This differentiation can lead to competitive advantages in operational efficiency, customer insights, and product innovation.

Adversarial AI Preparedness

The susceptibility of AI systems to adversarial attacks calls for robust testing and defense mechanisms. Companies specializing in AI security services could see increased demand as businesses seek to protect their AI investments from manipulation and exploitation.

Model Commodification

Open-source language models with commercial licensing, such as Databricks' Dolly, could disrupt the market by offering high-quality capabilities at a fraction of the cost. This commodification poses an existential threat to proprietary models from big tech companies.

WHEN WILL ARTIFICIAL INTELLIGENCE DISRUPT YOUR ORGANIZATION?

AI WILL DISRUPT EVERY INDUSTRY WITHIN THE NEXT FIVE YEARS

Drawing a parallel to Moore's law, which posits the doubling of transistors on microchips roughly every two years, there's speculation that AI's intelligence could follow a similar trajectory. If this is the case, several factors will drive this exponential growth in intelligence: enhancements in data quality, increasing computational power, and strides in algorithm efficiency, extracting more intelligence per unit of data and compute.

However, unlike the steady hardware advancements Moore's law describes, AI has the potential for self-improvement. As AI begins to self-improve and contribute to its own development, we may witness a self-reinforcing cycle of intelligence growth. This positive feedback loop means that AI's capacity to learn and evolve could accelerate, leading to profound impacts across all industries.

The inevitability of AI-driven transformation is not a matter of if but when. Our AI report is one section of our 2024 Tech Trends report, which offers in-depth coverage of 15 additional technology and industry sectors. Each industry section contains timelines that outline how AI, along with other emerging technologies, are expected to impact and influence that particular sector over time. Refer to the "When will AI impact your organization?" page to find details on specific timelines related to AI adoption and impact on your industry.

WHEN WILL ARTIFICIAL INTELLIGENCE DISRUPT YOUR ORGANIZATION?

Below, we highlight high level near-term developments to keep an eye on across industries.

Scaling
Enormous amounts of training data are still required for most AI models to learn. For example, recommender systems coupled with generative AI could lead to deep personalization for the hospitality and health care sectors—as long as data is made available. Historically, data is locked inside proprietary systems built by third parties, and regulation often hinders access to certain forms of data.

Investment
AI has passed through cycles of enthusiasm and disillusionment, leading to either too much or not enough capital being made available. Investors prioritize commercialization over basic R&D—though the latter yields bigger impact and often stronger returns. Investors's patience will influence progress and commercialization.

Constraints on adoption
Even if a technology is maturing, constraints on its adoption can hinder its impact on an industry. For example, a business may refuse to adopt an automated system because it challenges existing orthodoxy or an existing successful strategy. This is especially true in health care, insurance, and financial services.

Regulations
Advances in technology typically outpace regulatory changes. This has benefited AI, which until very recently was not targeted for regulation. Additionally, whether local regulations are conflicting or complementary, influences adoption in the marketplace.

Media mentions
Increased awareness and enthusiasm can influence the momentum of a technology, even when there's been no real breakthrough. Until OpenAI's ChatGPT breakthrough in late 2022, leaders weren't talking about the impact genAI might have on their business. Media bursts related to AI will drive momentum, especially if those stories are favorable, and more importantly, are easily understood by the public.

Public perception
How the public understands and responds to AI advancements will create or quell demand. This is especially true of generative AI and education/creativity/ intellectual property/misinformation, and the role assistive technologies will play in shaping the future workforce.

R&D developments
The pace of new research breakthroughs can't be scheduled to coincide with a board meeting or earnings report. Factors like funding, quality, and size of staff, and access to resources can improve the likelihood and speed of new discoveries. We closely monitor R&D developments but treat them as wild cards.

OPPORTUNITIES & THREATS

Threats

It's possible for agents to learn the right skills but the wrong objectives; an AI system can be asked to learn something that then could be used for harmful purposes. Commercial AI products could inadvertently incentivize bad behavior.

Publicly available LLMs are often the foundation for AI startups, but some researchers and technologists are questioning their defensibility when it comes to capturing value. The moat is in data. Techniques and models will largely get commoditized, and served via the infrastructure layer, where real value will be realized.

Long-term sustainability depends on network effects to gather enough user data. User-generated data can be harnessed to differentiate systems by offering tuned models on top of foundational/commoditized LLMs, creating a flywheel effect. Longer term, niche LLMs will be owned by a select few players, while general-purpose LLMs become commoditized.

The challenge of balancing data collection for workflow optimization with concerns of worker surveillance requires careful navigation by companies. AI's use and understanding of behavioral biometrics could be considered intrusive into deeply personal behaviors, often subconscious to the individual, starkly confronting worker privacy expectations.

Heightened protectionism across nations could escalate the costs of producing chips and other critical technologies, and make it more difficult to find the right talent. Companies should brace for the adverse economic impacts of geopolitical shifts as supply chains undergo realignment.

AI models might achieve assigned goals by any means necessary, including suppressing or hiding data. Systems are needed to identify when this happens—until then we risk using bad information to make decisions.

High-performing models are susceptible to "jailbreaking," where bypassing LLM limitations can lead to manipulations, resulting in unpredictable and potentially harmful outputs. Given that businesses and entire institutions are starting to rely on LLMs, jailbreaking represents an urgent security threat that has yet to be addressed.

Opportunities

AI is on track to become an indispensable tool for knowledge workers. The next 18-24 months will see the development of assistive technologies tailored to various professions, akin to GitHub's Copilot, but designed for financial analysts, commercial real estate developers, and lawyers.

Companies sitting on industry-specific data hold the cards to create powerful AI agents. In industries like law, finance, and other knowledge-based sectors, proprietary data can train more capable AI agents.

Within the next 18-24 months, generative AI will integrate into many consumer apps. Where clicks and keywords once dominated, intelligent assistants will guide users through voice and text. Personalized support gets weaved throughout experiences, changing how people engage with information.

AI models that understand language will lead to more devices that enable people to interact with technology through voice and conversation instead of screens. Opportunities await for companies quick to challenge status quo screen-centric form factors.

AI is going local. Wearables and endpoints of all kinds will be embedded with AI, from pets' collars that report on animals' activities, to smart home devices that understand and execute complex commands from natural language. Large language models will migrate on-device, perhaps in lieu of a conventional operating system.

The rising energy needs of AI could incentivize tech companies to adopt alternative, greener energy sources like nuclear and geothermal, potentially driving a shift toward sustainable energy independently of government mandates.

Open-source models allow businesses and developers to adapt and enhance foundational models for specific uses, saving the cost and effort of starting from scratch or investing heavily in data and training.

INVESTMENTS AND ACTIONS TO CONSIDER

1

Create domestic internship and apprenticeship programs to build talent pipelines in AI skills, where shortages loom. Partner with schools to develop a homegrown workforce proficient in these technologies vital for national strategic interests.

2

Investing in data centers powered by renewable energy or exploring partnerships with alternative energies like nuclear and geothermal could align AI operations with ESG goals, reducing the carbon footprint of data processing and storage, and reducing the cost of compute.

3

Nvidia dominates the GPU market, yet demand outpaces even its cutting-edge chips. With shortages routine, space exists for rivals while cloud partners hunger for inventory.

4

As AI models grow in complexity, investing in alternative computing architectures like neurosymbolic AI, processing-in-memory technology, and specialized AI chips for on-device processing could offer significant advantages in efficiency, speed, and privacy.

5

Build atop shared foundations. Open-source models like LLaMA and FLAN offer springboards to launch specialized solutions tuned to distinct industry needs. These specialized models are more accurate and focused to the industry they serve and give proper weight to relevant parameters.

6

Foster development of small language models (SLMs). Investing in the research and deployment of SLMs suitable for edge devices can open new avenues for AI applications in environments where cloud connectivity is limited or nonexistent. SLMs can significantly expand the reach of AI into everyday devices, enhancing user experience and functionality.

CENTRAL THEMES

New data sources are coming

The integration of hardware, particularly wearables, will redefine the landscape of data collection and utilization. Coming to market soon are an array of different wearable devices equipped with sensors, cameras, and speakers, and they represent a significant leap forward in our ability to gather real-time, contextual data. This evolution marks a future where the volume of data available for analysis will expand exponentially, offering unprecedented insights into consumer behavior and environmental interactions. The challenge for organizations won't just be in the collection, but in the sophisticated parsing and interpretation of this deluge of data, requiring advanced AI algorithms and analytical frameworks.

Race for AI hardware supremacy

The intersection of hardware development and geopolitical competition is reshaping the landscape of AI advancement, with implications spanning national security, technological sovereignty, and economic prowess. As governments worldwide vie to establish AI supremacy and reduce dependence on foreign technology, substantial investments are pouring into domestic chip fabrication and AI research. The US and China, in particular, are locked in a battle for technological dominance, with both nations allocating significant resources toward bolstering their respective chip capabilities and AI infrastructure. This geopolitical rivalry extends beyond economic competition, with ideological considerations shaping AI development strategies and regulatory frameworks. China's insistence on AI alignment with socialist values underscores its commitment to ideological control, while Russia perceives Western AI advancements as a threat to traditional values, driving efforts to develop indigenous AI solutions. Meanwhile, escalating tensions have catalyzed a bifurcation in the AI chip market, prompting countries to explore alternative chip architectures and supply chain diversification strategies. This unfolding chip war not only underscores the strategic importance of semiconductor technologies but also poses profound implications for global technological cooperation and innovation.

Chip shortages loom large

The surging demand for AI has highlighted the global supply chain's inability to meet the need for powerful chips essential for developing and deploying AI models. We predict a chip shortage, particularly for graphics processing units (GPUs), due to production issues and ongoing shipping challenges due to regional conflicts. Microsoft's recent annual report marked the scarcity of GPUs as a potential risk for investors, underscoring the critical role these chips play in AI development and the broader implications for companies and end-users reliant on AI technologies. The industry as a whole will grapple with limited supply and the challenge of meeting explosive demand, prompting a shift toward more efficient or alternative computational methods. Maybe that's why in February 2024, OpenAI CEO Sam Altman reportedly went on a business development tour seeking $7 trillion in investment to create an alternative to our current chips.

CENTRAL THEMES

Choosing between proprietary and open source

Last year, when Meta released LLaM, its suite of open source LLMs, there was a new debate about the benefits and risks of going open source. Organizations using large language models face a challenging decision: Go with the big names like OpenAI and Microsoft for easy access to top-notch tech but give up adaptability and transparency, or push up your sleeves and build your own tailor-made systems to ensure transparency and extensibility. Despite the steep development costs associated with proprietary LLMs, the open-source community has responded with notable alternatives, such as Databricks' Dolly LLM, which offers a solution at a fraction of the cost. The new shift toward open-source solutions aims to counterbalance the growing concentration of AI tools in the hands of a few major corporations, offering businesses the opportunity to integrate bespoke applications without compromising proprietary information.

Reckless era ends, oversight era begins

The era of "move fast and break things," and "build first, ask permission later" appears to be waning in Silicon Valley as regulatory scrutiny intensifies in response to growing concerns over AI's societal impacts. With initiatives like a US presidential executive order and the EU's AI Act, policymakers are striving to establish guidelines and restrictions to govern AI technologies, particularly in sensitive areas like facial recognition. However, crafting concrete policies that balance innovation with ethical considerations, poses significant challenges, and ensuring effective enforcement remains a formidable task. As governments grapple with the complexities of regulating AI, the tech industry faces a new era of accountability and responsibility for the products they create.

AI doomers distract

Amid the discourse surrounding AI, a contingent of pessimistic voices, often referred to as "AI doomers," has emerged, likely to persist in the foreseeable future. For business leaders, navigating this landscape proves challenging, as they are presented with polarizing narratives of either utopian ideals or dystopian anxieties, resulting in a nuanced yet unsettling reality. While it's crucial to remain vigilant against potential risks and mitigate them effectively, the prevalence of doomerism tends to overshadow constructive dialogue and proactive measures.

CENTRAL THEMES

Industry is building the future of AI, not academia

The landscape of innovation is shifting, with industry emerging as the primary driver of technological advancement, outpacing academia in the development of new machine learning models. Recent data reveals a stark contrast: in 2022, industry produced 32 machine learning models compared to academia's three, marking a significant departure from historical trends. Industry's dominance is further underscored by its access to abundant resources—large data sets, computational power, and financial capital—essential for creating cutting-edge AI systems. This transition is reflected in the career choices of AI Ph.D. graduates, with 65.4% opting for industry positions, compared to 28.2% in academia, a trend that has steadily widened since 2011. The exodus from academia to corporations could have a chilling, long-term effect on knowledge transfer from professors to students, which could negatively impact the future pipeline for the talent industry which will need to remain competitive.

AI widens global inequality gulf

The exorbitant costs associated with training language models are setting a precedent for the formidable expenses expected in developing image and video models, further accentuating disparities in resources between different regions and exacerbating the global divide between the affluent and less affluent nations. This trend not only reshapes the landscape of business and communities but also positions wealthy countries, notably the United Arab Emirates and Saudi Arabia, as potential hubs for AI development, potentially marginalizing opportunities for advancement in the global south.

ONES TO WATCH

Dr. Aidan Gomez, CEO and co-founder of Cohere, for proposing the novel neural network technique called the transformer that now underpins the generative AI era.

Arthur Mensch, Dr. Guillaume Lample, and Timothée Lacroix, co-founders of European generative AI upstart Mistral AI.

Dr. Andrej Karpathy, researcher at OpenAI for his research in deep learning and computer vision.

Clément Delangue, CEO and co-founder of Hugging Face, for creating an open-source, for-profit machine-learning platform.

Dr. Daniel Kang, assistant professor at University of Illinois Urbana-Champaign , for his research identifying potential harms from language models, including demonstrating language models' ability to autonomously interact with websites in concerning ways without human feedback, and his work to develop methods that promote the safe and ethical development of AI.

David Nippa, a doctoral student at Ludwig-Maximilians-Universität München, for the development of an AI model that can predict where a drug molecule can be chemically altered.

Dr. Dario Amodei and **Daniela Amodei,** CEO and president of Anthropic, for creating one of the world's leading AI labs.

Dr. David Rolnick, assistant professor of computer science at McGill University, for work on a framework for understanding the relationship of AI and greenhouse gas emissions.

Grimes, artist and musician, for championing new business models around AI for likeness leasing and creative experimentation.

Dr. Jaime Teevan, chief scientist and technical fellow at Microsoft, for spearheading the use of LLMs in Microsoft's core productivity products.

Jensen Huang, CEO, president, and co-founder of Nvidia, for navigating the growing geopolitical chip conflict.

Dr. Joelle Pineau, vice president of AI research at Meta, for developing new models and algorithms for planning and learning in complex partially observable domains.

Leopold Aschenbrenner, AI alignment researcher at OpenAI, for his contributions to AI alignment discourse.

Lila Ibrahim, COO of Google DeepMind, for leading the company's responsibility and governance work.

Marc Raibert, executive director at Boston Dynamics AI Institute, for his work to develop AI-driven robots that can reason.

Miguel Solano, co-founder and CEO of VMind, for his work to improve AI compute performance in GPUs using novel algorithmic techniques.

Dr. Ning Zhang, an assistant professor of computer science and engineering at Washington University, for the development of AntiFake, a tool that prevents unauthorized speech synthesis.

Dr. Prakhar Mehrotra, vice president for applied AI at Walmart Global Tech, for leading enterprise adoption of AI.

Robin Li, CEO, chairman and co-Founder of Baidu, which last year released Ernie Bot, an LLM on par with ChatGPT.

Dr. Ruogu Fang, an associate professor in the J. Crayton Pruitt Family Department of Biomedical Engineering, for his work to evaluate diagnostic bias in AI tools.

Sebastien Krier, international policy manager at DeepMind, for his research and intellectual contributions to AI alignment discourse.

Dr. Sune Lehmann, professor at the Technical University of Denmark , for research into the predictive capabilities of AI, specifically its potential to forecast events in an individual's life.

Dr. Swami Sivasubramanian, vice president of database, analytics, and machine learning at Amazon Web Services, for advancing cloud capabilities and insights for businesses.

Dr. Xin (Eric) Wang, assistant professor of computer science and engineering at Baskin Engineering at UC Santa Cruz, for the development of the Text to Image Association Test, a tool that measures complex human biases in text-to-image models.

Dr. Zhou Jingren, deputy director of Alibaba Damo Academy (Alibaba's bleeding-edge research arm), for leading AI initiatives related to smart cities, autonomous driving, mobile computing platforms, semiconductor R&D, and other areas.

IMPORTANT TERMS

MACHINE LEARNING (ML)

ML uses data to make predictions and recommendations on how to achieve stated goals. AI pioneer Arthur Samuel popularized the idea of machine learning in 1959, explaining how computers could learn without being explicitly programmed. This would mean developing an algorithm that could someday extract patterns from data sets and use those patterns to predict and automatically make real-time decisions. It took many years for reality to catch up with Samuel's idea, but today machine learning is a primary driver of AI's growth.

There are different types of machine learning, including supervised, unsupervised, and reinforcement.

Supervised learning

A model that attempts to transform one type of data into another type using labeled examples. Supervised learning is used when teams know how to classify the input data and what they are trying to predict, but can get accurate results much more quickly by relying on an algorithm rather than a human. This is the most common form of ML used today. Understanding what product features would most likely drive new purchases is a business use case for supervised learning.

Unsupervised learning

Data is provided to a model without specific output parameters, and the model tries to learn the data set's structure without any designated labels. For example, if a researcher doesn't know what to do with a large data set, an unsupervised learning model could determine patterns, classify data, and make recommendations without a human supervisor. Researchers used unsupervised learning during the pandemic to find patterns on how COVID-19 spread throughout communities.

Reinforcement learning (RL)

A system performs a task by repeatedly running calculations as it attempts to accomplish a stated goal. It's a trial-and-error process, where rewards or penalties are earned in response to the system's performance toward achieving the stated goal. RL is used when there isn't enough training data, when the researcher is trying to learn about an environment (such as a complex financial portfolio), or when the researcher needs to find greater levels of optimization. It has a high number of business use cases, ranging from real-time dynamic pricing models to high-frequency trading algorithms to the systems that operate self-driving cars.

DEEP LEARNING (DL)

Deep learning is a relatively new branch of machine learning. Programmers use special deep learning algorithms alongside an enormous corpus of data—typically many terabytes of text, images, videos, speech, and the like. Often, these systems are trained to learn on their own, and they can sort through a variety of unstructured data, whether it's making sense of typed text in documents or audio clips or video.

In practical terms, deep learning's emergence means that more and more human processes will be automated, including the writing of software, which computers will soon start to do on their own. For example, once a system learns what an object looks like—say, an apple—and then can recognize that object in all other images, even if it has only a partial view.

There are different types of deep learning architectures. The most common types include convolutional neural networks, recurrent neural networks, transformer neural networks, and generative adversarial networks (GANs).

Convolutional neural network (CNN)

A CNN is multilayered, with a convolutional layer, a pooling layer, and a fully connected layer. Each one performs a different task with the data. The output is classification. If a researcher has 10,000 images and needs to extract data—to recognize particular faces, for instance—the CNN would run until information could be inferred. In business, CNNs are used to identify anomalies in medical imaging, faulty products on a production line, blight on crops, and other irregularities.

Recurrent neural networks (RNNs)

These multilayered neural networks move and store information between input, hidden, and output layers. They are good at modeling sequence data for predictions. In business, they are used anytime the sequence of data matters, such as speech recognition and language translation. RNNs are used in digital assistants, to create captions for images, and to generate narrative reports using structured data (sports, financial).

Transformers

A transformer is a component whose purpose is to process sequential data, such as natural language or genome sequences. Transformers rely on "attention" (the mathematical description of how things relate to, complement, or modify each other) in translating sequences. A transformer neural network is the unique architecture that enables systems to learn from context and to generate new

IMPORTANT TERMS

information. Transformers are complementary to CNNs and RNNs, the two most common neural network architectures used in deep learning.

Generative adversarial networks (GANs)

As unsupervised deep learning systems, GANs are composed of two competing neural networks—a generator and a discriminator—that are trained on the same data, such as images of people. The networks compete against each other to perform a task, such as identifying the correct person, resulting in optimizing overall performance. GANs are useful when researchers don't have enough data to train an algorithmic model, and are also used to create new, synthetic data.

Deepfakes, which have become prevalent in the past year, are generated using GANs. In design, GANs are tremendously useful: They can produce thousands of designs and recommend the best ones based on pre-set parameters. They can generate and modulate voices, faces, even gestures. Researchers from Nvidia, Mass General Hospital, BWH Center for Clinical Data Science, and the Mayo Clinic collaborated on a GAN that generates synthetic MRIs showing cancerous tumors.

ADDITIONAL TERMS

Agents
In AI, agents are entities that perceive their environment and take actions autonomously to achieve specific goals.

AGI (artificial general intelligence)
A designation for systems that match and then exceed the full range of human cognitive ability across all economically valuable tasks.

AI safety
A field that studies and attempts to mitigate the catastrophic risks that future AI could pose to humanity.

Algorithm
A process describing how to solve a specific problem or how to complete a particular task.

Alignment
The process of ensuring that an AI's actions and goals are in harmony with human values and intentions.

ASI (artificial superintelligence)
ASI refers to an AI system that surpasses human intelligence and capability across all fields, including creativity, general wisdom, and problem-solving.

Automatic speech recognition
Algorithmic systems that give computers the ability to recognize and convert audio to human-readable language.

Chain of Thought
This involves a model processing information or solving problems step by step, mimicking human-like reasoning.

Computer vision
Processes that give computers the ability to derive meaningful information from digital images (including still and video) and to mimic and manipulate such images.

Foundation model
A large-scale AI model trained on vast amounts of data, capable of being adapted to a wide range of tasks without being trained from scratch.

Generative AI
GenAI refers to AI technologies that can generate new content, including text, images, music, and video, based on learned data patterns.

GPU
A graphics processing unit is specialized hardware designed to accelerate the creation and rendering of images and videos, often used in AI for parallel processing tasks.

Model
A program that has been trained on a data set. Models are generally used for analytical and decision-making tasks, such as making predictions.

Natural language processing
Processes that give computers the ability to understand, mimic, and manipulate human language.

Parameter
A variable internal to the model that the system adjusts during training to improve performance on given tasks.

Prompt
An input given to a model to elicit a specific output or response, guiding the AI in generating content or solving problems.

Recommender systems
A class of machine learning algorithms that uses data to predict, narrow down, and find what people are looking for among an exponentially growing number of options.

IMPORTANT TERMS

RHLF

Reinforcement Learning from Human Feedback is a training method where AI models are refined based on feedback or corrections provided by humans, enhancing their performance and alignment with desired outcomes.

Supervised learning

A type of AI training where models learn from labeled data, using known input-output pairs to predict outputs from new inputs.

Symbolic AI

Symbolic AI involves AI systems that use explicit, human-readable symbols to represent knowledge and perform logical reasoning to solve problems.

Training data

The data set used to teach AI models how to understand and perform tasks by identifying patterns, making decisions, or generating predictions.

Unsupervised learning

Unsupervised learning involves AI models identifying patterns and structures in data without any labeled outcomes, learning from the data itself.

XAI (explainable AI)

AI systems designed to provide human-understandable insights into their decision-making processes, enhancing transparency and trustworthiness.

Zero-shot learning

An AI approach that enables models to correctly handle tasks or recognize objects they have not seen during training, using understanding from related contexts.

MODELS, TECHNIQUES, AND RESEARCH

WHAT IS AN AI MODEL?

An AI model is a computational structure that is designed to perform tasks that would normally require human intelligence. This includes recognizing speech and images, interpreting visuals, translating between languages, and making decisions. There are several types of AI models, each suited to specific tasks and goals but at their core, all AI models rely on algorithms and mathematical frameworks. They are "trained" on large data sets so they can refine their internal parameters and improve at assigned tasks. As AI systems become more advanced, they require more data and computing power during this training process.

Constructing AI models is an enormously resource-intensive process, not comparable to traditional software development. Training a high-performance language model demands processing huge data sets to fine-tune millions of parameters. This mandates extensive computing power and specialist time measured in months or years. As a result, advanced models are predominantly built by tech industry leaders like Google, Microsoft, and OpenAI who possess the vast technical infrastructure and talent required. The consumer focus and profit motive within these companies have accelerated model innovation beyond academic efforts. Historically, academia was seen as the most likely source of groundbreaking AI. But the sheer data scale, computing power, and engineering capacity within industry, has proven far more efficient for allocation of resources.

Examples

Note: All of these examples are current as of March 1, 2024

ChatGPT-4

OpenAI's most recent model as of publication, GPT-4, doesn't just generate text—it can generate images from text and vice versa. It was trained on enormous data sets of text and images using reinforcement learning from human feedback (RLHF), which helped make the model more helpful and safer for users. Early benchmarks exhibit GPT-4's versatility on tasks from legal exams to adversarial truthfulness tests. On the Uniform Bar Exam, it scored 90% versus GPT-3.5's 10%, while reducing factual errors by 40% compared to ChatGPT. While hallucination risks still exist, GPT-4 marks substantial progress in mitigating failure modes.

Claude 2.1

Anthropic unveiled Claude 2.1, the latest in its series of language models, capable of processing significantly longer texts than OpenAI's GPT-4.

Gemini

After an underwhelming debut in 2022, Google iterated to the more impressive Gemini Pro in early 2024. This model demonstrates rapid advances, as evidenced by its meteoritic rise up the Hugging Face conversational AI leaderboard. Google's Gemini isn't just a single AI model—it encapsulates a suite of AI models for varied applications. Gemini Nano targets offline Android use. Gemini Pro now powers Bard and emerging enterprise services. Gemini Ultra is Google's most advanced large language model yet, designed to elevate search, advertising, and cloud products globally.

With the ability to manage up to 200,000 words or symbols, Claude 2.1 significantly surpasses GPT-4's limit of 128,000. The new iteration of Claude is designed to reduce the likelihood of generating inaccurate information compared to earlier versions. A significant enhancement in Claude 2.1 includes its ability to utilize tools and interface with APIs. Additionally, the introduction of system prompts allows users to define precise contexts for their inquiries, promoting more organized and reliable responses from the model.

PaLM 2

PaLM is a 540 billion parameter language model developed by Google AI. Smaller 8 billion and 62 billion parameter versions were also trained. PaLM demonstrates strong performance across common-

WHAT IS AN AI MODEL?

sense reasoning, math reasoning, humor, code generation, translation, and other tasks. The model highlights Google AI's advances in scalable transformer architecture research for language AI.

Whisper

Whisper is an open-source automatic speech recognition system created by OpenAI. First released in 2022, it was trained on over 680,000 hours of multilingual speech data scraped from the internet. Whisper can transcribe speech to text in multiple languages including English. It can also translate speech from non-English languages into English text. Compared to other publicly available systems, Whisper demonstrates leading speech transcription and translation capabilities. OpenAI has released the model freely for public use.

OpenAI's DALL-E 3

DALLE-3 is a text-to-image AI system that can create realistic art and images from textual descriptions. DALL-E is capable of generating images in various styles like photorealistic, paintings, and emoji. Without explicit prompting, the model can manipulate and rearrange objects as well as correctly position design elements in new compositions. These creative capacities demonstrate DALL-E's aptitude for controllable high-fidelity image generation.

Stability AI's Stable Diffusion

Stable Diffusion is a text-to-image generation model released in 2022 leveraging diffusion methodology. Primarily used to create detailed images from text prompts, Stable Diffusion can also perform tasks like inpainting, outpainting, and image-to-image translation driven by descriptive text inputs.

Midjourney

Midjourney creates visuals based on textual descriptions, known as prompts, akin to the functionalities offered by OpenAI's DALL-E and Stability AI's Stable Diffusion. A fake Midjourney-created image of Pope Francis wearing a puffer jacket went viral in 2023.

Open AI's Sora

In early 2024, OpenAI released Sora, an AI model that can create realistic and imaginative scenes from text instructions. Sora marks a significant advancement in AI's capability to execute human creativity by transforming brief text inputs into compelling videos up to a minute long, not only achieving realistic imagery but also emulating the dynamic essence of movies, similar to how ChatGPT mimics human conversation.

Google Lumiere

Google's Lumiere is a text-to-video diffusion model that creates video from a prompt with realistic motion. Utilizing a novel diffusion model named Space-Time-U-Net (STUNet), Lumiere excels in creating realistic video content by understanding both spatial placement and temporal movement within a video. Unlike other methods that assemble videos from individual frames, Lumiere crafts videos through a seamless integration of frames, achieving fluid motion across 80 frames—significantly more than its current competitors.

Pika

Pika is an "idea-to-video" platform to edit and create videos from text and still images. Pika includes features like text-to-video, image-to-video, and video-to-video conversions.

Users can ask the tool to create a video of a real person (e.g., "imagine Oprah as a Pixar cartoon"), ask the tool to edit glasses on a video of a donkey, or change the style of a video to something out of Studio Ghibli.

WHAT IS AN AI MODEL?

Purpose-Built Models

Organizations must decide whether to use ready-made general purpose AI models like OpenAI's GPT, or invest in developing custom models tailored to their industry and needs. General-purpose models like GPT are convenient "plug-and-play" solutions that can adapt to many tasks through fine-tuning. However, their flexibility is limited when it comes to specialized business challenges. Custom models built for a specific purpose can better master industry-specific challenges by training on aligned data and objectives. OpenAI now provides a simple way for users to create custom models through the GPT marketplace—users describe their requirements to ChatGPT, and it handles coding the new model. Custom GPTs can then be integrated into platforms and services, accessing databases, email, e-commerce, and more to automate workflows.

LLMs Are Getting Bigger and More Expensive

Because of their massive size and complexity, the cost of developing LLMs is high. Training these models can cost millions of dollars. DeepMind's Chinchilla, for example, reportedly cost around $2.1 million to train. Bloom, an open-access multilingual language model, is estimated to have required an investment of approximately $2.3 million. OpenAI hasn't provided public information about the cost to train ChatGPT-4, but many analysts estimate the earlier version of the model, GPT-3, could exceed $4 million.

As the number of parameters increases, so does the cost. Moreover, unlike traditional software, deployment costs remain high post-development. Operating large language models for inference still necessitates enormous compute for the billions of calculations involved per user query. Furthermore, contributing to the high price tag of training and running large language models demands specialized AI hardware, with graphics processing units (GPUs) now standard over traditional CPUs. Initially designed for gaming, GPUs are perfectly suited for handling the extensive data processing demands of AI, despite their high cost of thousands of dollars per chip. For example, Meta used 2,048 Nvidia A100 GPUs to train its LLaMA model on 1.4 trillion pieces of text over 21 days, which amounts to nearly 1 million hours of GPU time. If using public cloud services, this level of compute would cost approximately $2.4 million. Despite its impressive capabilities, with "only" 65 billion parameters, LLaMA is still smaller compared to larger models like OpenAI's ChatGPT-4, which has 1.76 trillion parameters.

LLMS as Operating Systems

A radical new concept for computing has emerged—an operating system powered by a large language model at its core rather than traditional programming. In this conceptual LLM-based OS, routine tasks could be automated and executed with an unprecedented level of sophistication, without the need for manual coding or intervention. The user interface would also be radically different than traditional operating systems. Rather than conventional graphical user interfaces or command line prompts, users could interact conversationally with the LLM through natural language requests and queries. For example, a user could say, "Please open yesterday's

While general-purpose models offer broad applicability, their limitations in specialized contexts are driving the development of models tailored to meet the unique demands of specific industries.
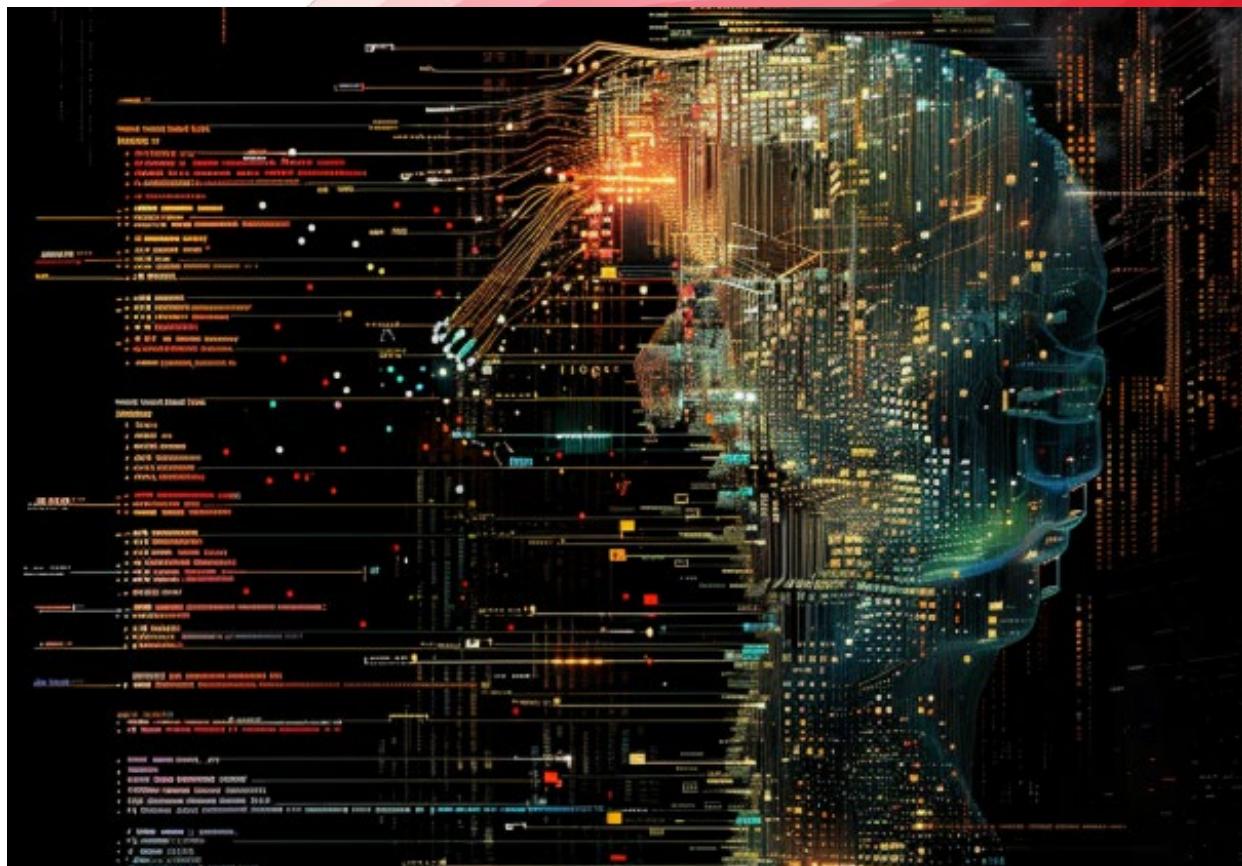
Image credit: Future Today Institute and Midjourney.

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sales report and format it as a slide presentation for my upcoming meeting." The LLM would comprehend these conversational commands and perform the necessary actions to carry out the desired tasks. It would execute complex workflows automatically by understanding users' intentions and goals. This could enable more intuitive, efficient interactions between humans and computers.

This concept has moved beyond theory into practical application, as demonstrated by Jesse Lyu, CEO and founder of Rabbit. Lyu launched the R1, a compact device about half the size of an iPhone, running on Rabbit OS— an operating system grounded in a LLM. Rabbit OS functions as a universal app controller, akin to systems like Alexa or Google Assistant, yet it offers a unique twist. It simplifies user interaction by removing the need to navigate through multiple apps or perform repetitive logins. Instead, users can directly communicate their needs to the device, and R1, understanding these natural language requests, efficiently executes the desired tasks. In early 2024, NVIDIA announced a personalized AI

chatbot for Windows RTX PCs that runs locally to connect users' data and queries to an open-source large language model. By keeping data on device rather than in the cloud, Chat with RTX not only delivers ultra-fast response times but also enhances user privacy and data security. The chatbot allows natural language interaction to search files so that users can simply ask, "What was that song my friend recommended while we were at the airport?" instead of manually searching through texts and email.

LLMs are becoming more central to human-computer interactions. As such, interfaces are shifting from search to conversational questions and answers in plain language.

Image credit: Future Today Institute and Midjourney.

SHOULD WE GO OPEN-SOURCE OR PROPRIETARY?

Companies that want to use LLMs must choose between proprietary or open source. Both have benefits and drawbacks. Proprietary LLMs from major tech companies provide easy implementation and leading-edge features. However, they lack transparency into how they work and have limited ability to customize them. Building a proprietary model internally gives companies more control over security, privacy, and tailoring the training to their specific data and needs. But this requires considerable expertise and time to develop. On the other hand, open-source language models promote transparency and flexibility at often lower, long-term costs. Yet if governance practices like testing for biases and false information are insufficient, they pose risks around issues like fairness, accuracy, and security vulnerabilities. When considering using LLMs, executives should think about cost, control, customization, and risk. There is no universally superior choice—rather, companies must weigh their priorities, capabilities, and constraints to determine if an off-the-shelf, customized, or open-source large language model approach best suits their situation.

> " We have our own nervousness, but we believe that we can manage through it, and the only way to do that is to put the technology in the hands of people.
>
> —Sam Altman, CEO of OpenAI

Proprietary examples:

OpenAI's GPT-4

Anthropic's Claude 2

Google's Bard

Open-Source examples:

Meta's LLaMA

RedPajama-INCITE

BigScience's Bloom

TII's Falcon

Open-Source LLMs for Commercial Use

Proprietary large language models cost millions to develop, which means high-quality capabilities are concentrated within wealthy tech giants. However, the open-source community has responded with surprisingly capable smaller models by fine-tuning them on quality data. For example, in March 2023 Databricks released Dolly—an open-source LLM trained for under $30 yet demonstrating conversational prowess rivaling ChatGPT. It was developed using Meta's open-source LLaMA LLM and fine-tuned with high-quality inputs from Databricks employees. The initiative aimed to provide an alternative to the increasing centralization of AI tools in a few large companies, focusing on an open-source chat model that permitted commercial use while protecting intellectual property and corporate information. Databricks not only open-sourced the training code, data set, and model weights for Dolly but also launched Dolly 2.0 in April 2023. Dolly 2.0 is open-source LLM licensed for commercial use, allowing companies to integrate their data with Databricks' data set to create bespoke applications without compromising their proprietary information.

SAFETY, ETHICS & SOCIETY

IS AI REALLY A BLACK BOX?

Many AI systems are opaque "black boxes" in how they work. Developers often withhold model and training details to protect IP. This lack of transparency perpetuates an impression that the systems have unknowable inner workings. Moreover, researchers themselves don't fully understand why AIs sometimes behave unexpectedly, owing to inherent complexity. While inputs and outputs are observable, the logic between remains nebulous. Thus some black-box qualities persist around advanced models' inner transformations, despite transparency efforts. So while more visibility into AI functionality and development is crucial for accountability and trust, uncertainties around emergent system behaviors may endure.

> "
>
> AI, like any technology, is a reflection of its creators and their intentions.
>
> —Joy Buolamwini,
> founder of the Algorithmic Justice League

Explainable AI (XAI)

Achieving full transparency into complex AI systems is difficult. However, the emerging field of explainable AI seeks to enable better human understanding of how algorithms function and arrive at outputs. Since complex machine learning models cannot act as total glass boxes, XAI instead seeks to provide interpretable visibility into significant aspects of functionality. This can involve revealing training data characteristics, delineating gaps in data coverage, auditing data collection fairness, detailing human involvement in model development, and highlighting key input features that drive outputs. A core focus is validating outcomes by surfacing how predictions, classifications and recommendations are supported to establish trustworthiness. Rather than eliciting every intricate internal model transformation, XAI pursues strategic explanations of the most critical workings—answering targeted questions about why and how certain results are produced. The objectives are accountability through limited but meaningful transparency, error checking via result explanations, and accessibility for a wider range of model users.

AI Intentionally Hiding Data

Computers do exactly as they are told. If you command a machine to win at a game, it will do everything in its power to achieve that goal. That's why researchers need to understand how AI reaches the end goal. It might be cheating to complete the task they were told to do. Researchers at Stanford University and Google discovered that an AI system designed to turn satellite images into usable maps was withholding certain data. The researchers were using a neural network called CycleGAN, which learns how to map image transformations. It took an old aerial photograph of a neighborhood, distinguished between streets, alleys, driveways, buildings, and lampposts, and then generated a map that could be used by GPS. Initially, they used an aerial photograph that hadn't been seen by the network. The resulting image looked very close to the original—suspiciously close. But on deeper inspection, the researchers found that many details in both the original image and the generated image weren't visible in the map made by the AI. It turns out that the system learned to hide information about the original image inside of the image it generated.

HOW DO WE ENSURE TRUST?

As AI is increasingly incorporated into more sensitive domains, pressing questions emerge.

How can we build AI that we can trust?

How can we trust AI's predictions and conclusions when much of the system is opaque?

How can we ensure that AI is aligned with human values, especially as it becomes more and more capable?

Could we inadvertently instruct a powerful AI towards harm?

Can we trust the current human custodians of this technology?

These pressing issues are at the heart of ongoing debates among AI ethics experts, where a definitive consensus on the best approaches has yet to be reached.

"

The biggest lesson learned is we have to take the unintended consequences of any new technology along with all the benefits, and think about them simultaneously—as opposed to waiting for the unintended consequences to show up and then address them. I don't think the world will put up anymore with any of us coming up with something where we haven't thought through safety, equity and trust—these are big issues for the world.

—Satya Nadella, CEO of Microsoft

AI Alignment Goes Mainstream

As AI systems improve, many researchers want guardrails to ensure that they are deployed in ways that do not harm humanity. AI alignment research refers to the process of ensuring that AI systems act in accordance with human values and goals. OpenAI, DeepMind, and Anthropic (which describes itself primarily as an "AI safety and research company") each have AI alignment teams with dedicated staff researching guardrails. While the total number of researchers working on AI alignment is small compared to the rest of the AI community, such dedicated teams did not exist until recently. The debate surrounding the alignment of AI with human objectives encompasses a broad spectrum of opinions. On one end, "AI doomers" view unchecked advancement, especially toward superhuman capabilities, as posing existential catastrophe risk—potentially including human extinction. They advocate solutions like indefinite moratoriums on large model training to forestall such outcomes. By contrast, the "effective accelerationist" perspective sees hastening progress as a moral imperative to quickly harness AI solving pressing global problems like disease, inequality, and climate change.

In the moderate middle lie a diversity of perspectives. Some, like economist Tyler Cowen, argue the doomers' risks are too narrowly specified for high probability, while others like Leopold Aschenbrenner from OpenAI's "superalignment team" make the case for substantial investments in AI alignment research, akin to "Operation Warp Speed" but focused on AI. This approach stems from the belief that artificial general intelligence (AGI) could become the most powerful tool ever developed, necessitating leadership in AI research by countries like the US to maintain a strategic advantage over nations such as China. These represent just a few of the myriad perspectives and it is likely that more perspectives will emerge before we converge on the right AI-alignment strategy.

Indexing Trust

We will soon reach a point when we can no longer tell if a data set has been tampered with, either intentionally or accidentally. AI systems

HOW DO WE ENSURE TRUST?
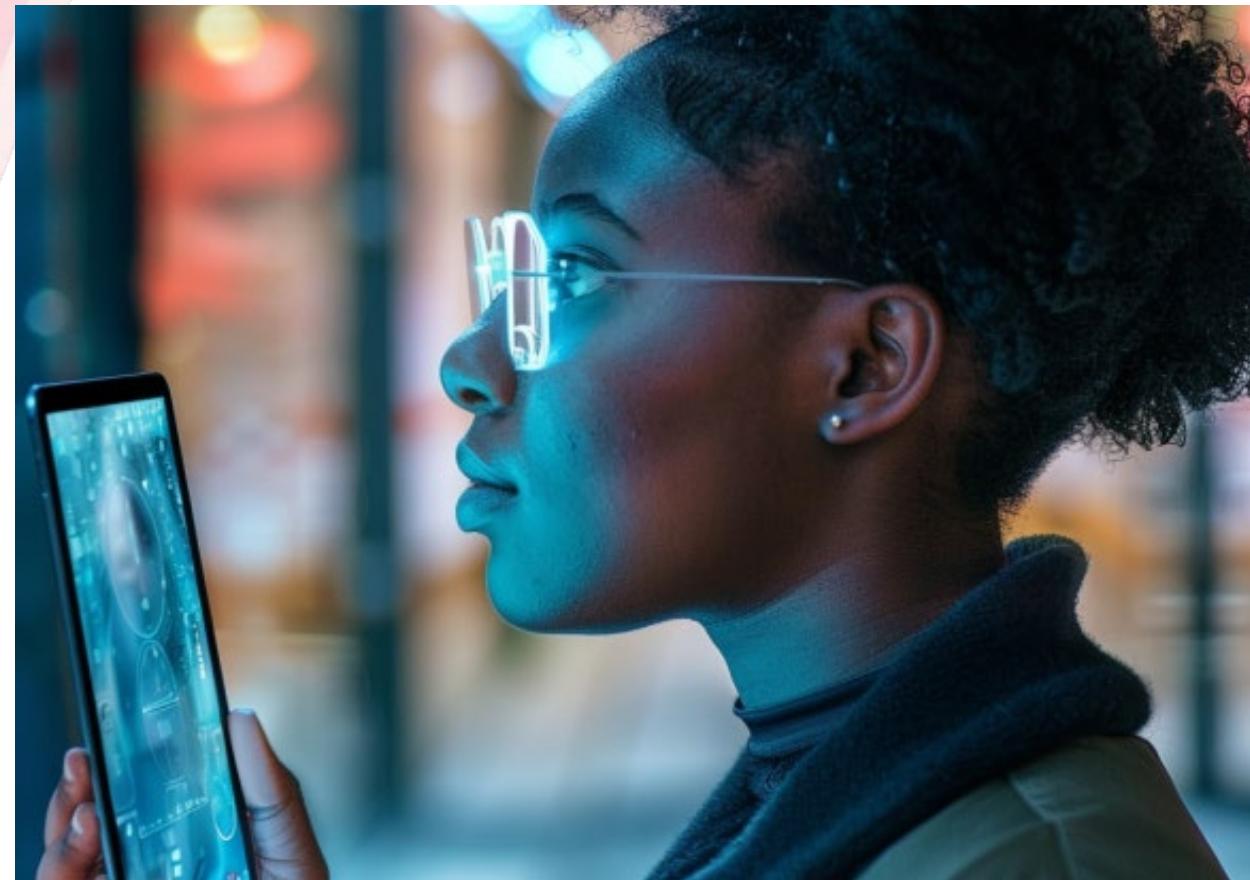
rely on our trust. If we no longer trust their outcomes, decades of research and technological advancement will be for naught. Leaders in every sector—government, business, nonprofits, and so on—must have confidence in the data and algorithms used. Building trust and accountability requires transparency and is a challenge, but there are efforts underway to assess AI transparency, a critical first step. Researchers from Stanford, MIT, and Princeton designed the Foundation Model Transparency Index (FMTI)—a scoring system that evaluates transparency across model development, functionality, and usage. The 2023 index places Llama 2 at the top, as the most transparent Foundation model, followed by BigScience's BloomZ and OpenAI's GPT-4. The hope is that by standardizing analysis of opaque systems, deployment risks and responsibilities can be better informed.

The ethics of how data is collected in the first place may also influence the trustworthiness and validity of scientific research, particularly in areas such as organ donations and medical research. In addition, employing ethicists to

work directly with managers and developers and ensuring diversity among developers—representing different races, ethnicities, and genders—will reduce inherent bias in AI systems.

Synthesizing Trust

Humans can be tricked into believing machine-generated faces, especially when they've been engineered to elicit trust. A study in the Proceedings of the National Academy of Sciences shows that synthetic faces are often "deemed more trustworthy than real faces," suggesting that synthetic faces could be designed as societal malware. If a bad actor was attempting to undermine institutions, it could deploy a synth on social media to sow distrust. There are not yet effective countermeasures for synthetic humans or effective markers to help consumers distinguish between fake and real.

The perceived trustworthiness of synthetic faces over real ones raises concerns about their potential use by malicious actors to erode trust in institutions.

Image credit: Future Today Institute and Midjourney.

ARE THERE TOOLS TO MAKE AI ETHICAL?

As AI systems become more advanced, making sure they are ethically deployed becomes increasingly important. For instance, AI can now generate hyper-realistic deepfake media that now passes the uncanny valley. This tech could let bad actors impersonate people or spread misinformation. AI can also be used for cheating, fraud, and hacking. In light of this, companies are emerging to create tools to combat this behavior. New tools can detect deepfakes, expose fraudulent AI activities, and implement preventative measures against misuse.

Deepfake Detectors

AI now enables creating highly realistic fake media called deepfakes—bogus video, audio, and text that seem real. They can spread misinformation by fabricating scenes or putting words in people's mouths. Researchers are developing protections against their misuse. Tools like AntiFake use imperceptible watermarks to block fake voice/face cloning before it happens. Platforms including Intel's FakeCatcher and European vendor Sentinel catch manipulations in real-time using AI. As deepfakes get better and better, surpassing the "uncanny valley," so does the market opportunity for exposing them. Expect to see more investment in this space.

Tools for Identifying AI-Generated Writing

AI is good at writing like a human. That means we need tools that can distinguish between human and AI-written content. DetectGPT is one such tool, offering over 95% accuracy in identifying whether a passage is written by a human or an AI system like GPT-3. Similarly, OpenAI itself has released a classifier that flags AI-generated text 26% of the time,

while maintaining a 9% false positive rate on human writing. These tools are essential in contexts where distinguishing between human and machine authorship is critical, such as in academic integrity, journalism, and legal documentation.

Tools for Detecting Copyright Violations in AI Outputs

With AI models capable of memorizing and reproducing content from their training data, the risk of copyright infringement becomes a significant concern. Researchers from Google, DeepMind, ETH Zurich, Princeton, and University of California, Berkeley have demonstrated this with the Stable Diffusion model, which can emit memorized images, including those with trademarked company logos. To combat this, watermarking techniques are being developed. For instance, the University of Maryland proposes a technique for watermarking language model outputs, making synthetic text algorithmically identifiable. Google DeepMind's SynthID tool embeds digital watermarks directly into image pixels, enabling the identification of AI-generated images while remaining invisible to the human eye.

Tools for Exposing Deepfakes

Hyper-realistic deepfakes pose significant security risks. Researchers at Washington University created a tool called AntiFake, which can add a digital watermark to content that proactively prevents the cloning of voices and faces. Intel's FakeCatcher and Sentinel use deep learning to analyze media content, catching manipulations either in real time or highlighting alteration patterns after creation. One significant concern regarding many deepfake detection tools is that they demonstrate bias. Studies have uncovered significant disparities in the error rates of deepfake detection algorithms across different racial groups. In one study, the difference in accuracy reached as high as 10.7%. This bias could lead to severe implications, such as genuine images of certain racial groups being mistakenly identified as fakes or, conversely, manipulated images being wrongly accepted as authentic. Dr. Siwei Lyu and a team at the University of Buffalo have developed what are considered to be the first deepfake detection algorithms specifically designed to mitigate bias. Their approach involves two machine learning methods: one

ARE THERE TOOLS TO MAKE AI ETHICAL?

that makes algorithms aware of demographic factors and another that works to blind them. These methods have successfully reduced disparities in accuracy across different races and genders. Notably, this achievement was not at the expense of overall accuracy; in some cases, accuracy was even enhanced. By focusing on the fairness of the algorithms, Lyu's work marks a significant step toward creating more equitable and reliable deepfake detection technologies, ensuring accuracy is independent of factors like race or gender.

Tools to Thwart Recognition Systems
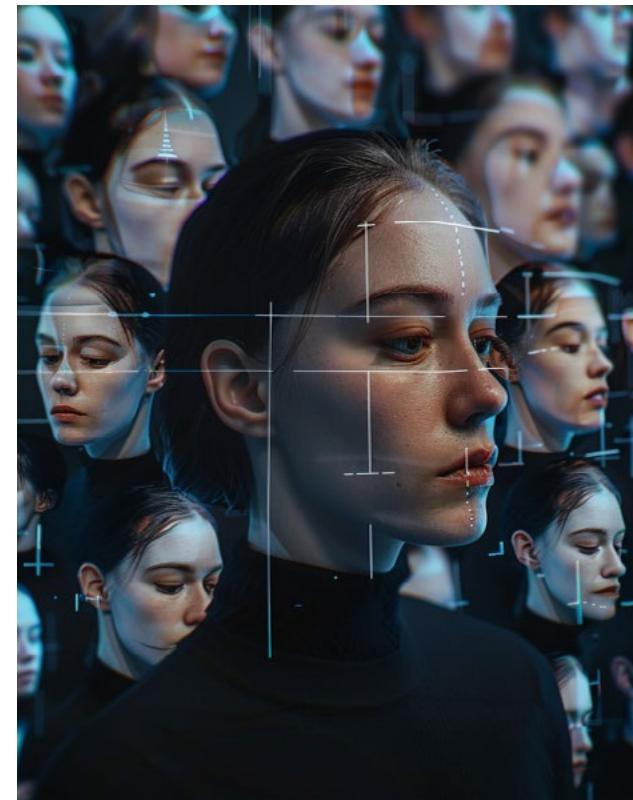
As facial recognition becomes ubiquitous, various groups want to limit the technology's effectiveness to protect privacy. While methods of confusing or obscuring facial recognition systems are not always feasible, researchers are trying to confuse online applications that scrape and collect images used as inputs for training facial recognition engines in order to develop a form of camouflage, which consumers may someday demand.

Researchers from the University of Chicago have created a program, Fawkes, that adds extra pixels to images to cause facial recognition apps to misclassify faces. Taking this principle a step further, Israeli company Adversa AI adds noise, or small alterations, to photos of faces, causing algorithms to detect a different face than what is visible to the naked eye. The algorithm is successful at imperceptibly changing an individual's image to someone else of their choosing.

Tools to Combat Broadly Malicious AI Behavior

Research labs around the world are actively working to build practical safeguards against malicious AI behavior. DeepMind has introduced a comprehensive toolkit and workflow designed to enhance the evaluation of standard models that can identify when AI is misbehaving according to human ethical standards. This approach specifically focuses on identifying and assessing potentially hazardous capabilities, like cyber-offense and self-replication, as well as the likelihood of causing harm.

Meanwhile, Anthropic has unveiled its Responsible Scaling Policy, which includes a detailed list of safety commitments based on risk assessments and incorporates pauses in development if safety measures fail to match the pace of capability advancements. The policy encompasses several key components, including internal access controls, adversarial testing (red-teaming), evaluations by independent third parties, and graded access based on different AI Safety Levels.

Researchers are working on ways to alter facial images so facial recognition systems misidentify the faces, potentially allowing people to avoid identification by these surveillance technologies.

Image credit: Future Today Institute and Midjourney.

DOES AI INFRINGE ON PRIVACY?
HOW SHOULD WE THINK ABOUT CUSTOMER DATA AND AI APPLICATIONS?

AI enables new forms of pervasive surveillance that could threaten personal privacy across several domains. Last year, facial recognition company Clearview AI said it had run more than 1 million searches for police in the US. Somewhat less obviously, ambient monitoring can now subject household environments to observation. Workplace analytics can track detailed employee behaviors and productivity. Schools can actively monitor students through devices and platforms meant for remote education. As private spaces face increasing exposure from third-party tracking, a culture of Big Brother–like awareness becomes normalized, rather than valuing independence and consent.

Increased Used of Ambient Surveillance

What happens behind closed doors may not be secret for long, and executives should beware of new ambient surveillance methods. Scientists at MIT discovered how to use computer vision to track data from what they call "accidental cameras." Windows, mirrors, corners, houseplants, and other common objects can be used, along with AI, to track subtle changes in light, shadows, and vibrations. The result: We all may soon have X-ray vision capabilities—which may not be great news for companies working on sensitive projects. Those working in information security and risk management should pay special attention to advances in computer vision.

Worker Surveillance

The rise of remote work during the pandemic accelerated the surveillance of workers, and will likely continue to grow as remote and hybrid work models take root. The US Constitution's Fourth Amendment, which prohibits unreasonable searches and seizures and precludes most uses of this same technology by law enforcement, doesn't apply to private companies.

Teleperformance, a French-based company that manages outsourced call center work for many Fortune 50 companies, uses cameras and AI to monitor its teams. It flags employees as idle when it detects they haven't used the keyboard or mouse within a specified time frame. Live Eye Surveillance offers a monthly subscription service that remotely monitors live video feeds of employees for companies such as 7-Eleven, Dairy Queen, and Holiday Inn. Sneek is another example of "tattleware" that captures live photos of employees via webcams and displays them on a digital wall viewable by everyone in the company. Click on a photo and it instantly pulls that person into a video call with you.

The most well-known user of worker surveillance might be Amazon, which has installed AI-enabled cameras in delivery trucks to track behavior. The company docks driver pay if it perceives unsafe conditions such as distracted driving, speeding, or hard braking. In its warehouses, the company monitors worker productivity by measuring what's called "time off task," which is any time when a worker isn't actively processing products. South Korean e-commerce giant Coupang, which has pledged to become the "Amazon of Korea," uses similar surveillance tactics.

The industry has also continued to evolve as it offers more AI-based analysis of workers. Amazon is exploring using keystroke-logging software that tracks user behavior over time to detect if the same person is controlling the worker's account. Aware's Spotlight software detects behavioral changes like mood, tone, and attitude across conversations on employees' devices. Teramind offers software that will disable private conversations if it detects "inappropriate" keywords. With the top three tools in the industry accounting for over 60% of global demand, expect to see more AI-based surveillance that leverages the growing pool of data collected by a variety of companies.

School Surveillance

During the pandemic, many students were issued laptops and other devices by schools to
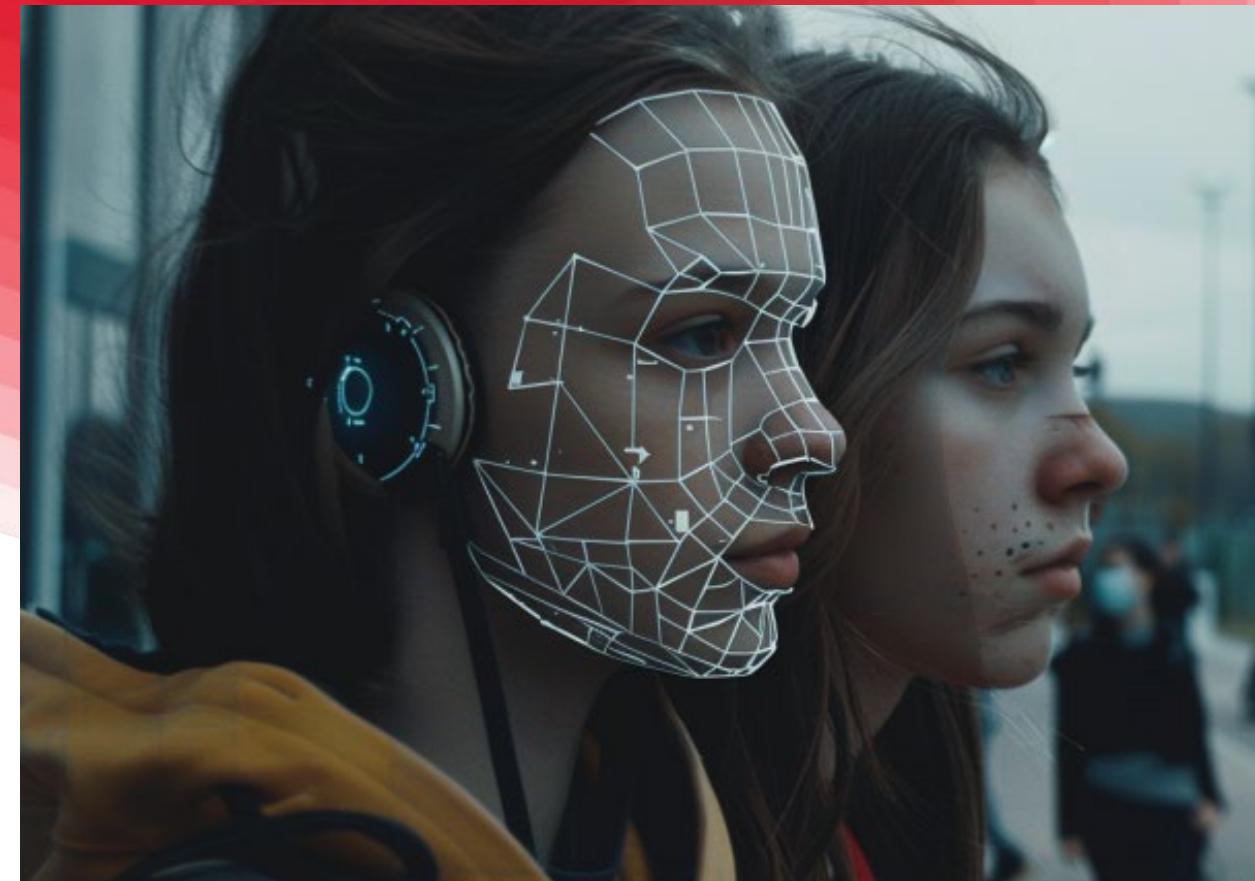
DOES AI INFRINGE ON PRIVACY?
HOW SHOULD WE THINK ABOUT CUSTOMER DATA AND AI APPLICATIONS?

facilitate remote learning. They weren't told, however, that these devices would open a portal into their homes that could be monitored by schools at all times of the day. In the US and many other countries, schools can legally monitor students, often without disclosing what is being tracked.

Gaggle is one company that monitors school-issued accounts and uses AI to track online behavior of students across services like email and chat tools. In 2020, the Minneapolis school district signed a contract with the company to monitor its students through 2023. A school district in California contracted with Securly to monitor students in real time, looking for prohibited behaviors such as having too many browser tabs open. The software enables teachers to close tabs for any students they believe are "off task."

Philadelphia and Chicago schools deployed GoGuardian software on district-issued Chromebooks. A vulnerability in the software allowed teachers to start virtual sessions that enabled webcams on those Chrome-

books without notification or consent by the student. Schools in China deploy technology to monitor attentiveness in students. An algorithm called 4 Little Trees is used in Hong Kong to detect students' emotions as they learn—by monitoring their facial expressions with webcams. If the system detects a lack of focus, it nudges the student to pay attention.

AI introduces pervasive surveillance capabilities, jeopardizing personal privacy in schools, workplaces, and public spaces. Society appears to be prioritizing convenience over privacy, accepting significant trade-offs.

Image credit: Future Today Institute and Midjourney.

IS THERE A FEASIBLE SOLUTION TO BIAS?

Seemingly the moment OpenAI's ChatGPT went public, there were multiple accounts of the system displaying racism, ageism, gender bias, and political bias. But it's not just ChatGPT—many AI systems have been revealed to contain bias—much of which can be attributed to the data that the systems were trained on. Given AI's expanding integration into sensitive domains like finance and health care, failing to address its potential biases risks compounding real-world discrimination through algorithmic means.

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The future of AI should be a mirror to society. It must be shaped by a diverse range of voices, not just those of technologists.

—Meredith Whittaker,
    cofounder of the AI Now Institute

Addressing Political Bias

In 2023, many conservatives raised concerns about ChatGPT's political bias, sharing screenshots of ChatGPT's left-leaning responses. OpenAI responded with a detailed blog post explaining its moderation approach, and CEO Sam Altman hinted at future possibilities for users to fine-tune ChatGPT iterations within certain broad guidelines, potentially sidestepping some contentious value judgments. Elon Musk, responding to these critiques about OpenAI's political correctness, launched a new venture, called TruthGPT, aimed at exploring "deeper truths about the universe." Separately, in an effort to make a point about biased AI, David Rozado, a data scientist from New Zealand, created DepolarizingGPT. This AI chatbot generates three types of responses for each prompt: left-wing, right-wing, and a neutral or integrating perspective. To achieve this, Rozado fine-tuned the chatbot using content under fair-use provisions from various sources. For the left-wing responses, he used material from publications like The Atlantic and The New Yorker, and authors like Bill McKibben

and Joseph Stiglitz. Conversely, the right-wing responses were shaped using content from outlets such as National Review and The American Conservative, and writers like Roger Scruton and Thomas Sowell.

Doubts regarding ChatGPT's ability to avoid bias persist. A new research paper claims to find substantial evidence of systematic political bias in ChatGPT, favoring Democrats in the US, Lula in Brazil, and the Labour Party in the UK. The paper analyzed ChatGPT's responses to statements from the Political Compass test, concluding that it aligns more with liberal parties internationally. However, the study's methodology and findings are not without criticism. Some researchers argue that the way ChatGPT was tested doesn't reflect typical user interactions and may not accurately represent the AI's behavior. Additionally, a data scientist, Colin Fraser, discovered that reversing the order of parties mentioned in prompts resulted in opposite biases, suggesting potential flaws in the study. These findings illustrate the complexities in assessing AI bias and the need for greater transparency from developers like OpenAI.

IS THERE A FEASIBLE SOLUTION TO BIAS?

Addressing Race and Gender Bias

There are significant challenges related to race and gender bias in AI. A notable instance occurred in December 2022, when Steven T. Piantadosi of University of California, Berkeley revealed a bias in ChatGPT's programming, which incorrectly associated scientific proficiency with being white or Asian male. OpenAI quickly addressed this issue, programming ChatGPT to reject the notion that race or gender should influence perceptions of scientific ability. However, this incident underscores a broader, long-standing problem of bias within AI systems.

In another study, researchers at the University of Florida examined racial bias in machine learning algorithms used for diagnosing bacterial vaginosis (BV), a common infection in women of reproductive age. The study, led by faculty members Fang and Ivana Parker, analyzed data from 400 women across four ethnic groups—white, Black, Asian, and Hispanic. They found that the accuracy of BV diagnosis varied significantly among these groups, with

Hispanic women experiencing the highest rate of false positives and Asian women the most false negatives.

To quantify bias, another team from Baskin Engineering at University of California, Santa Cruz, led by Assistant Professor Xin (Eric) Wang, developed a tool called the Text to Image Association Test. It quantifies bias in text-to-image (T2I) AI models like Stable Diffusion, by measuring the variance in images generated from neutral versus gender-specific prompts. The findings indicate that such state-of-the-art models not only reflect but can also amplify existing human biases. Such analysis represents crucial progress toward accountability, but much work remains to ensure AI equitability.

After ChatGPT launched in 2022, researchers quickly discovered biases in its programming that linked scientific proficiency to white or Asian male gender and race, underscoring the broader issue of unfair biases that can become ingrained in AI systems. To address this, developers are proactively testing models for biases and making concerted efforts to train more equitable, inclusive AI.

Image credit: Future Today Institute and Midjourney.

WHAT SECURITY ISSUES SHOULD WE PREPARE FOR?

AI introduces security threats of unprecedented complexity due to its ability to learn and adapt, making traditional security measures less effective. Its integration across critical infrastructure and sensitive systems means that AI-driven attacks can have far-reaching and unpredictable consequences. Additionally, the sophistication of AI enables the creation of highly targeted and convincing cyberattacks, such as deepfakes and advanced phishing attempts, challenging our ability to distinguish between genuine and malicious communications. For example, recently, advanced language models have grown so smart that they can now use tools, read documents, and even call on themselves, acting independently. If AI models can hack websites on their own by finding and exploiting weaknesses without being taught specific vulnerabilities, what does that mean for the future of cybersecurity resilience?

> " AI lowers the barrier for novice cyber criminals, hackers-for-hire and hacktivists to carry out effective access and information gathering operations. This enhanced access will likely contribute to the global ransomware threat over the next two years.
>
> —U.K. National Cyber Security Centre January 2024 Assessment

Cyberthreats

The National Cyber Security Centre (NCSC) released an assessment in 2023 on the near-term impact of AI on cyberthreats. The NCSC assessment delves into how AI will likely enhance the volume and severity of cyberattacks in the next two years, mainly through the evolution of existing tactics. AI is being used by various cyberthreat actors, including state and non-state entities, to varying degrees. The report suggests that AI will significantly improve capabilities in areas like reconnaissance and social engineering, making them more efficient and harder to detect. However, more sophisticated AI uses in cyber operations will likely remain limited to actors with substantial resources and expertise in AI and cyber technologies. The assessment concludes that AI's impact on cyberthreats is uneven and depends on the capability and intent of the threat actors. It also points out that the proliferation of AI-enabled cyber tools in criminal and commercial markets is likely to further enhance these capabilities.

Adversarial Attacks

Recent studies highlight a significant vulnerability in AI to adversarial attacks, revealing that these systems can be more easily manipulated to make incorrect decisions than previously understood. These adversarial attacks involve deliberate tampering with the data input into AI systems, causing them to misinterpret information or act in unintended ways. For instance, specific patterns or objects, like certain stickers on a stop sign, can trick an AI in autonomous vehicles into not recognizing the sign. Similarly, alterations in medical imaging data could lead an AI to diagnose incorrectly.

This issue was the focus of a study by Tianfu Wu and his team at North Carolina State University, which examined the prevalence of such vulnerabilities in AI deep neural networks. Their findings suggest that these adversarial vulnerabilities are far more widespread than previously recognized, posing a significant challenge to the reliability and safety of AI applications. In a separate study by researchers at Carnegie Mellon University,

WHAT SECURITY ISSUES SHOULD WE PREPARE FOR?

the vulnerability of AI chatbots to adversarial attacks was demonstrated. By modifying prompts with specific strings of text, which may appear nonsensical but hold particular significance for AI models trained on extensive web data, the researchers could bypass the safeguards designed to prevent chatbots from generating inappropriate content. This approach effectively "unshackled" the AI, making it possible for chatbots like ChatGPT, Google's Bard, and Claude from Anthropic to respond to otherwise restricted or harmful queries. The success of these attacks across multiple popular AI chatbots suggests a deeper, more systemic weakness in the most advanced AI systems, challenging the deployment and safe use of these technologies.

Data Poisoning: A Double-Edged Sword

Data poisoning attacks represent a significant threat to AI systems, where malicious actors deliberately manipulate the training data to mislead the AI into making incorrect or harmful decisions. These attackers exploit vulnerabilities, such as embedding harmful content within files, to introduce misleading

data into the training set. This can skew the AI's learning process, aligning it with the attacker's goals, potentially leading to biased outcomes, data breaches, or simply inaccurate AI outputs. To illustrate, consider the cost implications: Training a complex AI model like GPT-3 can cost around $17 million. If its training data were compromised, restarting the process could lead to substantial financial losses.

On the flip side, data poisoning can also serve as a defensive mechanism. A novel tool named Nightshade exemplifies this dual nature. Designed to protect artists' intellectual property, Nightshade subtly alters digital artwork's pixels. When AI models use this "poisoned" art for training, their ability to accurately interpret images is compromised, leading to erroneous outputs, such as mistaking a car for a cow. This tool is part of a broader strategy for artists to safeguard their work in an unregulated landscape. Artists can use Nightshade via Glaze, another tool from the same creators, which masks an artist's style—transforming a realistic

drawing into a cubist style, for example. This integration allows artists to choose between masking their style or actively using the data-poisoning feature.

AI Lowers the Barrier to Misinformation

AI has lowered the bar to produce and distribute misinformation. An analysis by News-Guard, a Microsoft tool that shows trust ratings for over 7,500 news and information websites, found that websites hosting AI-generated bogus reporting have ballooned over 1,000% in the past year, mushrooming from 49 to over 600 outlets. While fabrication used to require armies of workers or advanced intelligence agencies, AI democratizes deception. Now a lone teenager can concoct sites and stories that appear authentic. And generative AI allows customizing fakery to particular targets and contexts with minimal effort. A study by the University of Waterloo found that an early version of ChatGPT, when tested on different types of statements including facts and misconceptions, often made errors, contradicted itself, and repeated false information. For example,

it could correctly state that the Earth is not flat when asked directly, but show inconsistency in its responses. Researchers expressed concern over these findings, highlighting the danger of AI models like GPT-3 spreading misinformation, especially as they become more common in use.

This is particularly concerning as we approach the 2024 US presidential election, with misinformation experts raising flags about the potential impacts on democratic processes. Ominous previews have already played out abroad. Shortly before a crucial national election in Slovakia, a controversial audio clip spread on social media, purporting to feature Michal Šimečka of the Progressive party discussing a vote-rigging plan. Another incident involved a fake recording of the UK Labour Party leader verbally attacking a staffer. Both recordings, which seemed authentic, were later exposed by fact-checkers as AI-generated fakes, highlighting the growing issue of AI-manipulated audio in spreading misinformation.

WHAT SECURITY ISSUES SHOULD WE PREPARE FOR?

Privacy Risks in Behavioral Biometrics

Behavioral biometrics, which employs machine learning to analyze a vast array of biometric data points, raises significant privacy concerns. By quantifying subtle aspects of our behavior, such as the force used on touchscreens, the distinct way we tap letters like "Cs" and "Vs," or our unique patterns when using a physical keyboard, these tools can reveal intricate details about our identities, thoughts, and future actions. While the technology offers potential benefits like enhancing security and possibly eliminating the need for passwords by identifying individuals through their typing patterns, it also introduces substantial risks.

The very aspect that makes behavioral biometrics appealing—its ability to authenticate a user based on nuanced behavioral traits—also makes it a privacy concern. If our behavioral patterns can be so precisely monitored and analyzed, they can be replicated or exploited, leading to new forms of security vulnerabilities. The notion that machines can detect and record behaviors we're not even conscious of ourselves not only challenges our concept of privacy but also highlights how these patterns, once considered personal and private, can become accessible and potentially misused. This duality presents a critical challenge: balancing the innovative applications of behavioral biometrics against the imperative to protect individual privacy and ensure the security of personal data.

AI can track unconscious patterns in human behaviors like typing cadence and keyboard pressure to derive insights about inner emotional states without explicit user permission.

Image credit: Future Today Institute and Midjourney.

WHAT DOES AI HAVE TO DO WITH ESG?

AI operations, particularly those involving deep learning and complex model training, are significantly more computationally intensive than traditional computing tasks. This intensity stems from the need to process vast amounts of data and perform countless calculations rapidly to train models, recognize patterns, and make decisions. Consequently, AI demands considerably more energy to sustain these operations, as the intricate algorithms and large-scale data processing require substantial computational resources, leading to higher energy consumption compared to conventional computing workloads. On the other hand, AI is also helping solve environmental issues. A Canadian startup, Rail-Vision Analytics, developed AI software that helps train engineers drive more efficiently, potentially saving significant amounts of diesel fuel and reducing the rail industry's carbon emissions. This technology, which is like Google Maps but for trains, advises engineers on when to speed up or stay idle, optimizing fuel use and contributing to a potential annual reduction of over 20,000 tons of carbon emissions if widely adopted, equivalent to removing more than 4,000 cars off the road each year.

New Architectures to Make AI Workloads More Efficient

As AI models become more complex and larger, consuming a greater share of our computing resources, their energy usage also escalates. One promising approach to make AI-intense compute more energy efficient is by using photonic AI chips, which harness light rather than electricity for orders-of-magnitude better efficiency at matrix multiplications—a core operation for deep learning. A Stanford team recently achieved a milestone by training an optical neural network chip to label data points with 98% accuracy. For the first time, their photonic processor enabled light to flow bidirectionally to implement the backpropagation algorithms vital for training. While refinements remain, this demonstrates the promise of optical computing to slash the carbon footprint of AI workloads.

Neuromorphic chips offer another model of efficient AI hardware, taking inspiration from the human brain's simultaneously distributed storing and processing of information. Rather than shuttling data back and forth like conventional computers, neuromorphic processors like Intel's Loihi store memory within computation. Specializing in sensory processing, these chips already achieve 1,000x higher efficiency than traditional hardware for tasks like gesture and sound recognition.

In a groundbreaking approach, researchers envision biocomputers powered by networked human brain organoids—essentially mini-brains grown from stem cells. "Organoid intelligence" holds significant potential for augmenting computing capabilities while concurrently addressing the escalating energy consumption demands driven by advancements in artificial intelligence and supercomputing (see the Computing report for more information on organoid intelligence). Despite traditional computers' ability to process calculations at speeds far surpassing human capabilities, human brains demonstrate superior performance in complex decision-making tasks, such as differentiating between a dog and a cat. Running AI on organoids could be the key to achieving human-like complex decision-making in an energy-efficient manner.

WHAT DOES AI HAVE TO DO WITH ESG?

A Nuclear Renaissance for AI Workloads
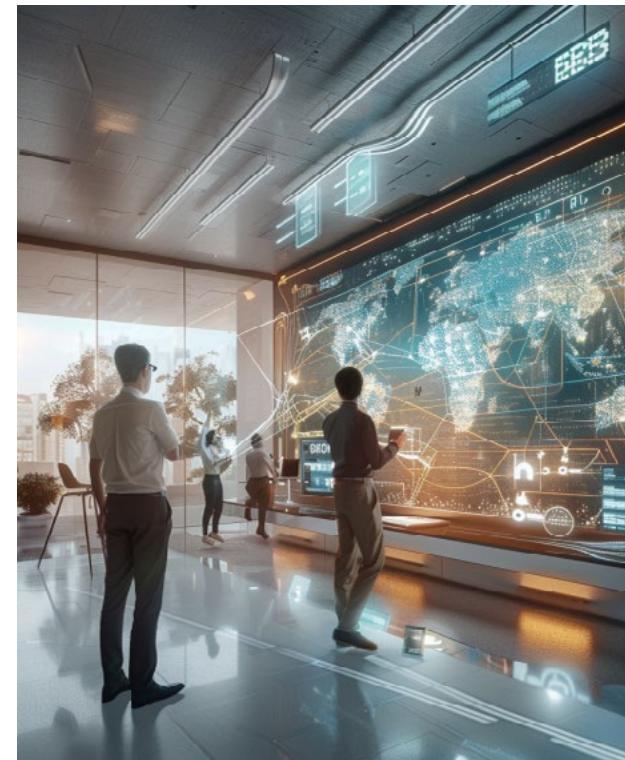
The monumental computational requirements of advancing AI could catalyze a nuclear power renaissance. Microsoft is exploring the use of next-generation small modular nuclear reactors (SMRs) to power its data centers and AI operations. SMRs promise cheaper, faster modular construction compared to traditional nuclear plants, which are often over-budget and delayed. Microsoft's approach was hinted at further in the fact that they already have a deal to buy Clean Energy Credits from Ontario Power Generation, which is on track to be the first utility to deploy an SMR in North America. Companies like Rolls-Royce, Last Energy, NuScale, Oklo, and TerraPower (backed by Bill Gates) are also developing various SMR models. Similarly, Kärnfull Next in Sweden plans to use SMRs to power data centers. The pivot toward nuclear energy, particularly next-generation SMRs, is a strategic response to the dual challenges of meeting the high energy demands of AI and achieving climate goals.

Environmental AI

AI presents a dual-edged sword in its impact on the environment, with its capabilities extending to both contributing to and alleviating climate change. David Rolnick from McGill University and Mila—Quebec AI Institute, notes that while AI's energy consumption and the promotion of consumerism through AI-based advertising may exacerbate climate challenges, it also offers solutions for environmental conservation. For instance, AI is being utilized to monitor and curb deforestation effectively.

A recent paper from the Cary Institute of Ecosystem Studies highlights how principles from ecology could inspire a new wave of AI development. This synergy between AI and ecology is seen as a pathway to address pressing global issues like disease outbreaks, biodiversity loss, and the repercussions of climate change. AI's application in ecology is already proving beneficial, aiding ecologists in detecting patterns within vast data sets to make precise predictions, like identifying potential human-infecting viruses and their animal hosts. In a practical demonstration of AI's environmental applications, a research team from the University of Waterloo has developed an AI tool, PlasticNet, to identify microplastics with unprecedented speed and accuracy. This technology is particularly crucial for mitigating the environmental and health hazards posed by microplastics, commonly found in food and water sources. By enhancing the efficiency of identifying these pollutants, PlasticNet supports wastewater treatment and food production industries in making informed decisions to protect the environment and public health.

While AI's computational demands pose sustainability challenges, it can also enable climate mitigation - models can guide efficient resource usage, accelerate green tech R&D, and predict environmental impact.

Image credit: Future Today Institute and Midjourney.

POLICY AND REGULATIONS

HOW DOES GEOPOLITICS FACTOR INTO THE DEVELOPMENT OF AI, AND IS THERE REALLY A NEW COLD WAR?

Countries are increasingly nationalistic about advancing domestic AI capabilities, with major investments and restrictions aimed at getting an edge, even as collaboration fractures. This extends into military contexts, where AI drives rapid innovations in areas like weapons systems, wargaming, and cyber operations—innovations dual in nature for both defense and potential offense. The combination of deteriorating cooperation and uncontrolled AI militarization risks fueling a dangerous tech-centric arms race. Unless cooperative norms are established, AI may drive global strategic realignments as impactful as 20th century nuclear and space races.

"

After Nagasaki and Hiroshima, it took 18 years to get to a treaty over test bans and things like that. We don't have that kind of time today."

—former Google CEO Eric Schmidt, on the urgency to create guardrails for AI.

AI Nationalism

Governments are racing to establish national AI champions and reduce reliance on foreign technology. After high-profile chatbot debuts like ChatGPT spawned in the US, 2023 witnessed nations worldwide scramble to nurture domestic AI capabilities, allocating tens of billions in funding. France unveiled substantial funding for startup Mistral. India's Krutrim launched the country's first multilingual model. Abu Dhabi commercialized its Falcon system. Beyond economic impacts, concerns mix technological prestige with national security and ideological control. The US and China are at the forefront of this tug-of-war, each pledging billions toward AI investments. While US companies are pioneering the most advanced LLMs, the US government is concentrating resources on growing homemade chip capabilities, aiming to lessen reliance on imports critical for national security. Concurrently, the US has imposed stringent export controls to limit the dissemination of advanced AI technology to rivals like China and Russia. With Western companies barred from exporting cutting-edge AI chips, adver-

sarial states invest heavily to replace blocked supplies. China has earmarked hundreds of billions to develop domestic chip fabrication immune to US sanctions. The Chinese government has invested heavily in replicating the chip supply chain domestically, aiming to insulate itself from Western sanctions. *See "The AI-Driven Chip War" for more.*

China also approaches AI on ideological grounds. The country mandated that AI align with the "core values of socialism," effectively limiting the influence of Western-developed AI systems within its borders. This stance has propelled Chinese tech giants like Alibaba and Baidu to develop their own generative AI tools, despite challenges in matching the impact of their Western counterparts. Russia also perceives American AI advancements as a cultural and ethical threat, with President Vladimir Putin highlighting the dangers posed by Western LLMs to Russian "traditional values." This reflects a broader concern over AI's potential to shape cultural and ethical norms, prompting Russia to explore the development of homegrown AI solutions.
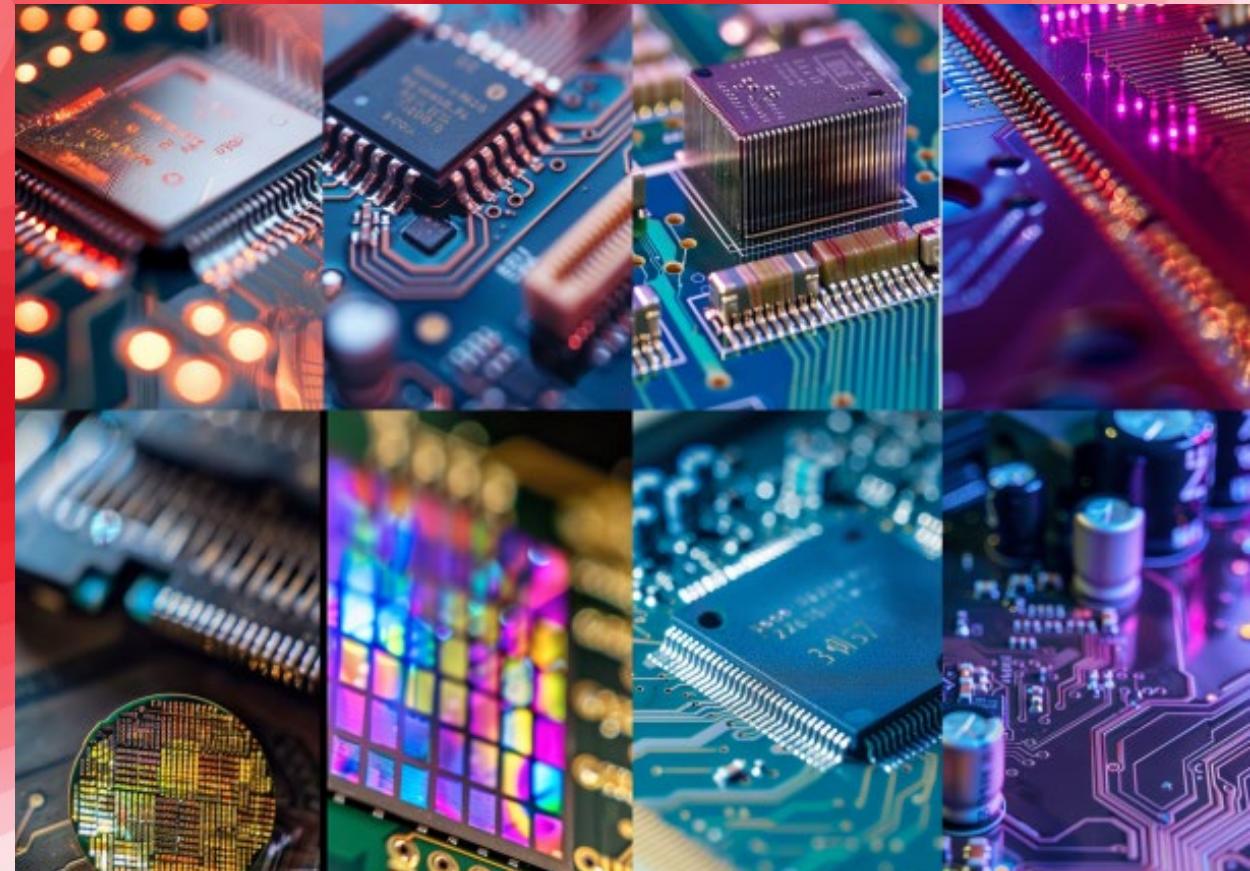
HOW DOES GEOPOLITICS FACTOR INTO THE DEVELOPMENT OF AI, AND IS THERE REALLY A NEW COLD WAR?

The AI-Driven Chip War

Rising tensions between the US and China are catalyzing a supply chain schism for the AI chips critical to national competitiveness. This divide has been exacerbated by strategic moves such as the CHIPS Act and increasingly stringent export controls, which have particularly targeted the semiconductor sector—a vital component of AI development. Efforts by companies like Nvidia to adapt by launching China-specific chips were thwarted by new US restrictions, leading Chinese companies to turn to domestic suppliers such as Huawei. Additionally, Dutch firm ASML canceled shipments of advanced semiconductor manufacturing equipment to China under US pressure, highlighting efforts to curb China's access to crucial AI development technologies. The standoff has prompted China to explore alternatives like RISC-V, an open-source chip architecture, as a means to bypass international restrictions. This move has sparked debate in the US about the potential risks of technology transfer and the feasibility of restricting contributions to RISC-V due to its global, royalty-free nature.

The intensification of the Chip War is leading to a bifurcation in the AI chip market, with potential long-term implications for global technological advancement and cooperation. This divergence not only underscores the strategic importance of semiconductors in national security and AI development but also hints at the emergence of distinct technological spheres, each aligned with divergent national values and priorities.

The chip war could force a seismic restructuring of international manufacturing supply chains, trade flows, and technology innovation networks.

Image credit: Future Today Institute and Midjourney.

COULD AI BE INVOLVED IN—OR CAUSE—A HOT WAR?

Advancements in artificial intelligence are reshaping modern warfare in unprecedented and concerning ways. Militaries worldwide are exploring how to best leverage AI for tactical advantages, including through autonomous weapons systems, wargaming simulations, and automated hacking tools. However, these technologies raise pressing ethical issues and could dangerously escalate conflicts. The complex tradeoffs surrounding AI and defense boil down to a central tension: harnessing potential benefits to national security versus controlling for geopolitical risks.

Autonomous Weapons Policies

The US Department of Defense recently updated its guidance on autonomy in weapons systems. The original 2012 policy, and a 2017 update, did not explicitly mention AI. The DOD updated its AWS definition by removing references to a "human operator" and replacing it with simply "operator," a subtle yet notable shift clearing the way for future systems with decreased human oversight. This new directive is aimed at helping to clarify the process for developing autonomous or semi-autonomous weapons systems. Previous policies, such as the Ethical Principles for Artificial Intelligence (2020) and Responsible Artificial Intelligence Strategy and Implementation Pathway (2021), were intended to guide decision making for the development and deployment of AI within the military.

The policy change comes on the heels of other recent government actions addressing military AI. In late 2022, NATO released its Autonomy Implementation Plan, arguing AI systems offer clear opportunities for alliance members while outlining a roadmap for adoption. Additionally, the First Committee of the UN General Assembly adopted a draft resolution in 2023 calling for the UN secretary-general to conduct a comprehensive study of lethal autonomous weapons. The committee instructed the secretary-general to consult member states and civil society on addressing humanitarian, legal, security, technological, and ethical concerns related to autonomous weapons.

Simulating Warfare

Given the rising tensions between the US and China over Taiwan, several groups are building AI-powered simulation tools to wargame a future conflict. In China, the People's Liberation Army has been using AI simulation tools to prepare for military operations against Taiwan.

The Center for Strategic and International, a bipartisan, nonprofit policy research organization, developed a wargame involving an amphibious invasion of Taiwan. After 24 rounds of gameplay, the US and its allies Japan and Taiwan successfully defeated a conventional amphibious invasion by China. While Taiwan remained autonomous in the simulation, its economy was devastated and the US lost hundreds of aircraft and tens of thousands of lives––while the Chinese Communist Party never really destabilized. Games that use real-world data to run simulations are augmenting the work of military strategists, so that leaders can validate or revise their postures on deterrence, invasion, and defense.

AI Used to Guide Military Strikes

In 2021, the US military said that it had started using AI to guide its airstrikes, deploying algorithms to a live operational kill chain. The kill chain is a process of gathering intelligence, performing analysis, weighing risks, and deploying weapons to destroy a target. Using a modified process, an AI system was deployed into the Air Force Distributed Common Ground System to analyze troves of intelligence, which would have required a significant amount of human hours to complete. The new AI system cannot order a strike on its own, but it is now automatically identifying possible targets.

COULD AI BE INVOLVED IN—OR CAUSE—A HOT WAR?

Automated Target Recognition

Lethal autonomous weapons systems, powered by AI, are capable of finding targets autonomously and making decisions to complete a mission. In 2022, a lieutenant colonel in the Ukrainian military said that he and a group called Aerorozvidka had developed special drones that make use of automated target recognition. While it's unclear whether Aerorozvidka actually carried out test missions, the fact remains that machine learning–based vision for automated target recognition already exists. In response, 70 nations delivered a joint statement at the UN General Assembly calling for a ban on autonomous weapons––but little progress has been made in the months since.

Automating Offensive Attacks Using AI

Thanks to advancements in AI, one of the big trends in security is automated hacking— in short, software that's built to out-hack the human hackers. DARPA launched a Cyber Grand Challenge project in 2016, with a mission to design computer systems capable of beating hackers at their own game. DARPA

wanted to show that smarter automated systems can reduce the response time—and fix system flaws—to just a few seconds. Spotting and fixing critical vulnerabilities is a task that might take a human hacker several months or even years to complete, and yet the machine that won the Grand Challenge did it in just a fraction of that time.

The winner became the first nonhuman entity to earn the DEF CON's Black Badge, which is the hacking community's equivalent of an Oscar. Very soon, malicious actors will create autonomous systems capable of automatically learning new environments, exposing vulnerabilities and flaws, and then exploiting them for gain—or whatever the stated objective, which could simply be generalized mayhem.

AI-Assisted Situational Awareness
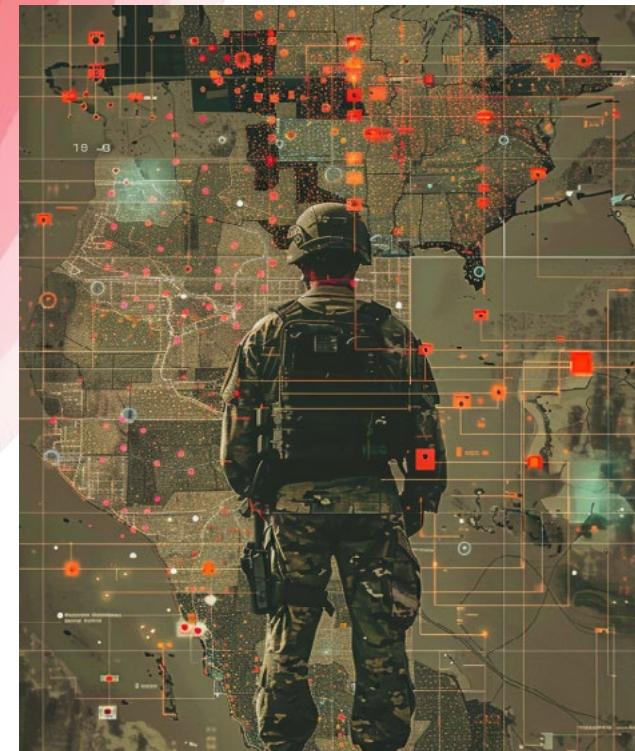
Ukraine has become a test bed for modern AI-enabled battlefield awareness. Geospatial intelligence leverages neural networks to combine satellite imagery, social media posts, and other open-source data into stra-

tegic insights. By fusing photographs, drone footage, and overhead views, AI integrates distinct perspectives into a unified assessment of terrain and enemy movements.

This augmented analytics empowers a new paradigm of cost-effective warfare centered around drones. Affordable models either commercially sourced or improvised as DIY drones generate valuable intelligence rivaling America's far more expensive Reaper and Predator UAVs. Tight integration with cutting-edge systems like Delta further multiplies impact. After proving effective in 2022 trials, Ukraine greenlit Delta's full-scale February deployment. Pulling sensor, aerial, and ground reports into a consolidated data lake, this cloud-based architecture furnishes commanders with an integrated common operating picture for tactical decisions.

Algorithmic Warfighting

Future wars could be fought entirely in code, using data and algorithms as powerful weapons. The current global order is being shaped by artificial intelligence, and the

AI is enabling the development of weapons that can select targets and attack on their own. The UN General Assembly has called for banning this type of autonomous attack technology, but so far there has been no ban put in place.

Image credit: Future Today Institute and Midjourney.

COULD AI BE INVOLVED IN—OR CAUSE—A HOT WAR?

same countries leading the world in AI research—the US, China, Israel, France, Russia, the UK, and South Korea—are also developing weapons systems that include at least some autonomous functionality.

In 2020, the US Air Force successfully flew an AI copilot on a U-2 spy plane in California, marking the first time in the history of the DOD that an AI algorithm trained to execute specific in-flight tasks was deployed. With the call sign ARTUµ, it was the mission commander—though the flight was just practice.

Future Today Institute analysis shows that the future of warfare encompasses more than traditional weapons. Using AI techniques, a military can "win" by destabilizing an economy rather than demolishing countrysides and city centers. From that perspective, China's unified march to advance AI puts the emerging superpower dangerously far ahead of the West.

Mandating Ethics Guidelines for Tech Contractors

Project Maven was developed to enlist AI to analyze surveillance video. Initially, Google was the DOD's vendor, but when employees found out they'd been working on a military project, thousands protested. It wasn't the first time tech contractors had lost trust in the government.

As a result, the Defense Innovation Unit is enforcing "responsible artificial intelligence" guidelines that vendors must adopt when building AI systems, models, or applications for the DOD. The guidelines offer specific instructions that must be followed during planning, development, and deployment, which include provisions for risk assessment. This represents a longer-term trend: government agencies requiring transparency in AI projects.

The future of warfare may largely involve fighting via cyberattacks powered by AI systems rather than conventional physical weapons. Militaries have started using AI as co-pilots in spy planes and drones, pointing to increased AI integration in defense.

Image credit: Future Today Institute and Midjourney.

REGIONAL APPROACHES

COUNTRIES TRY TO REGULATE AI, BUT PLANS DIVERGE

Governments worldwide are trying to balance maximizing AI's benefits with mitigating its risks by establishing regulatory frameworks. So far, 31 countries have passed AI regulations and 13 more are debating AI laws. There are significant divergences between each country's distinct approach to regulating the technology. Some nations, like Israel, Japan, and Australia, have focused on revising existing laws to facilitate AI development, while others, like the UAE, are crafting broad national AI strategies with minimal regulatory emphasis. Countries, like Russia, Iran, North Korea, Syria, and Iraq, have opted to outright ban specific services like ChatGPT. The EU's AI Act categorizes systems by risk levels and restricts the highest risk applications. Like the EU, China has introduced AI-specific

legislative frameworks, but unlike the EU, the frameworks are centered on enforcing "socialist core values" in AI. Brazil's draft AI policies prioritize user rights and risk assessments, differing from Israel's model underscoring responsible innovation and sector-specific oversight. The UAE's national strategy concentrates heavily on expanding AI integration rather than regulation.

On October 9, 2023, the US Bureau of Industry and Security of the Department of Commerce added 28 Chinese entities, including eight leading technology companies, to its entity list for their involvement in human rights violations against Uighur Muslims in Xinjiang, a move that China condemned as interference in its internal affairs. This listing requires US companies to

obtain licenses before exporting certain technologies to these entities, aiming to address national security concerns without automatically imposing a full embargo, reflecting a significant effort to regulate the flow of sensitive technologies to organizations implicated in unethical practices. The impact on these Chinese companies and China's AI industry could be disastrous, depending on enforcement measures and these companies' reliance on US technology, worsening US-China relations.

These complex tensions parallel past situations like GDPR in Europe, where large multinational companies often end up defaulting to the most stringent regulations globally even if not universally binding. This scenario could plausibly unfold with

major players standardizing elements of higher-bar AI governance models like the EU's for consistency. The lack of alignment across the proliferating patchwork of national and regional AI laws risks hampering innovation and global collaboration. But ironing out conflicts poses immense challenges given different priorities surrounding development versus human rights and ethics.

HOW IS THE US SPECIFICALLY REGULATING AI?

The explosion of AI technologies is leading to both fascination and concern among federal legislators, who are now exploring regulatory responses without a clear consensus. Last October, the Biden administration issued an executive order to ensure the safe and trustworthy development and use of AI, covering a wide range of AI systems beyond just generative AI and neural networks, affecting organizations across all economic sectors. Going forward, the National Institute of Standards and Technology (NIST) will play a key role in establishing guidelines for AI systems, prompting organizations to assess their use of AI and their reliance on AI-enabled products and services from third parties, and to align their AI risk management frameworks with NIST standards. But for now, there is no clear enforcement mechanism in place to check for compliance. Meanwhile, Congress is deliberating how to approach AI's dual-edged sword of opportunities and challenges, as it looks to local legislatures for precedents. So far, more than 30 states have enacted laws addressing AI in diverse ways, from specific policy concerns to establishing bodies for studying AI's impact. Senate Majority Leader Chuck Schumer and others have emphasized the need for AI regulation through initiatives like the AI Insights Forum, signaling a bipartisan understanding of its necessity. Some lawmakers consider the European Union's AI Act a model for comprehensive regulation, suggesting that the US might follow with a similar framework to manage AI's growing influence in society. State laws vary, focusing on consumer data privacy, combating AI-driven discrimination, especially in hiring practices, and addressing the manipulation of media in elections, with some states already implementing or proposing legislation to restrict deceptive AI-generated content. The US will likely adopt a bottom-up patchwork quilt of AI regulations instead of one sweeping law, like the EU's AI Act. The US government will likely boost spending on AI and AI research, especially in defense and intelligence, and use its buying power to shape the market.

A Patchwork Approach

In the US, the approach to regulating AI amounts to a diverse array of regulations that vary by state and sector, creating a patchwork framework rather than a unified national strategy. This decentralized approach results in differing standards and guidelines across jurisdictions, complicating compliance for organizations operating in multiple states and sectors within the AI landscape. Consider the current landscape of proposals and policies below.

Bias

The Algorithmic Accountability Act, a notable congressional proposal, would mandate companies to evaluate their algorithmic systems, including AI, for bias, effectiveness, and other factors if passed. Under the act, the Federal Trade Commission would be tasked with enforcing these evaluations, with a focus on preventing the use or sale of racially biased algorithms. However, the specifics of the FTC's enforcement strategy remain undefined.

HOW IS THE US SPECIFICALLY REGULATING AI?

Several US states and the District of Columbia are enacting or proposing legislation to prevent AI and algorithmic decision-making tools from reinforcing societal discrimination. Laws are being passed primarily in Democratic-led states, focusing on areas like insurance, employee surveillance, and hiring practices. For instance, Colorado mandates insurers to disclose and manage risks of algorithm use to ensure fair coverage. Massachusetts is considering a ban on AI-based employee surveillance technologies. In D.C., proposed laws would restrict service eligibility decisions made by algorithms and require user notification about how their data is used. Additionally, New York City and some states are addressing AI's role in hiring, requiring bias audits and transparency in the use of automated decision systems.

Copyright
The US Copyright Office has ruled that AI-generated content typically doesn't qualify for copyright protection as it's not human-created. But this could change now that tools like Sora pose new threats to the film industry.

Privacy
Proposals at the federal level include a complete prohibition on using personal data for targeted advertising and FTC-mandated data minimization, restricting websites to collect only data pertinent to their specific functions. At the state level, at least 12 states have enacted regulations governing automated decision systems, including AI, for profiling consumers based on personal data. Virginia's 2021 Consumer Data Protection Act is a pioneering example, mandating risk assessments and consumer rights protections when entities process over 25,000 people's data for profiling posing heightened harm risks. States are increasingly following Virginia's model by instituting similar regulatory frameworks surrounding data-driven automated systems. Additionally, some jurisdictions like New York City are specifically restricting AI usage in hiring practices through measures like bias audits and candidate notifications when screening algorithms are deployed.
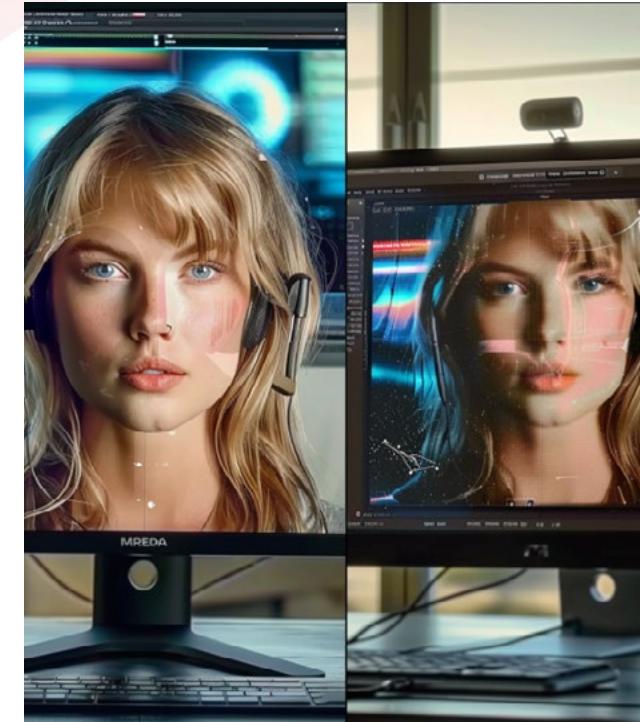
Deepfakes
The US National Defense Authorization Act includes provisions that address the growing problem of deepfakes, requiring the Department of Homeland Security to issue an annual report for the next five years on the risks posed by deepfakes. In 2021, the US Senate Committee on Homeland Security and Governmental Affairs voted unanimously to advance the Deepfake Task Force Act, which would establish a public-private team to investigate technology strategies and to develop policies that could curb risk.

Numerous states, including California, Texas, Minnesota, and Washington, have enacted laws, while New York, New Jersey, and Michigan have proposed legislation, aimed at either prohibiting or requiring disclosure of manipulated media. Many of these measures are intended to prevent public deception regarding political candidates or to influence election outcomes.

Misuse
The topic of auditing misuse is also on the

The US government is concerned about the potential misuse of deepfake technology, especially with elections approaching, which is why the latest National Defense Authorization Act includes new provisions aimed at tackling the challenges posed by increasingly realistic synthetic media.

Image credit: Future Today Institute and Midjourney.

HOW IS THE US SPECIFICALLY REGULATING AI?

congressional agenda. Legislators like Sens. Ted Budd and Ed Markey are pushing for the Department of Health and Human Services to assess AI's biological risks and develop strategies against its use in bioweapons or artificial pandemics.

Licensing

The concept of licensing requirements for AI, akin to the stringent regulation of food and pharmaceuticals, is gaining momentum. Inspired by Andrew Tutt's 2017 proposal, this approach suggests an agency could enforce pre-market approval for algorithms in certain applications, effectively requiring a government license before public deployment. Prominent figures like OpenAI's Sam Altman, Rand Corp.'s Jason Matheny, and New York University's Gary Marcus have supported such licensing, drawing parallels with the Food and Drug Administration's model.

Compute

In October 2023, the Bureau of Industry and Security introduced updated rules to enhance its October 7, 2022, regulations. These revisions focus on closing loopholes in the existing policy, further limiting China's access to advanced AI semiconductors and manufacturing tools. This move strengthens the US strategy to impede China's military AI development.

Conflicting Views About Institutional Roles

Debate persists over whether new institutions should be formed to oversee AI development and safety, or if this responsibility should fall to existing agencies. Proponents of new institutions argue they could have a major positive impact, just as bodies like the National Transportation Safety Board did for transportation safety. Suggestions for new AI oversight bodies include a National Algorithms Safety Board to monitor and ensure safety in algorithmic and AI systems, a federally funded National Artificial Intelligence Research Resource (NAIRR) to support and coordinate AI research, an international collaborative facility modeled after CERN to attract top global AI talent and focus efforts on pursuing AI safely, and an organization similar to the International Atomic Energy Agency (IAEA) to govern superintelligence efforts and safe AI deployment worldwide. A 2020 law has already mandated the creation of a task force to design NAIRR.

However, others argue existing institutions could handle AI oversight without requiring new bureaucracies. Examples include government bodies like the National Institute of Standards and Technology, FDA, Securities Exchange Commission, and Federal Communications Commission, as well as beefing up AI and tech expertise within established scientific institutions such as the Department of Energy, National Science Foundation, and NIST. Critics argue new institutions may not be more effective than today's agencies, citing issues faced by analogous bodies like IAEA in comprehensively monitoring relevant technologies globally. There are also questions around feasibility of meaningfully tracking AI development as opposed to physical materials.

At least 12 states have passed laws mandating government or related entities to research AI to enhance understanding and assess potential impacts. While some of these initiatives delay targeted regulation, others have led to tangible steps. For instance, Vermont's Artificial Intelligence Task Force's analysis resulted in the state's Division of Artificial Intelligence, which annually reviews AI usage and its effects within state government.

Public-Private Partnerships

The abundance of AI job listings across practically every American industry signals surging demand for related skills. The White House has issued a call for AI talent to join the federal government, following President Biden's executive order for the safe, secure, and ethical development and use of AI. This initiative seeks experts to help implement AI technologies across various government sectors to enhance services, ensure AI safety and equity, and maintain the country's leadership in AI innovation. Many US fabs, which are funded in part by the Chips Act, face construction delays because of a shortage of skilled workers.

The US has enlisted allies like Japan, the

HOW IS THE US SPECIFICALLY REGULATING AI?

Netherlands, and Germany to tighten their own export regimes. While competing nations pursue more centralized strategies, the US distinctive edge lies in decentralized AI innovation across promising startups and tech giants alike.

Large companies have always lobbied to influence policy and regulation. But as the tech giants amass power and wealth, they are making key decisions that impact diplomacy and geopolitics.

Big Tech companies are standing up departments dedicated to geopolitics. Microsoft President Brad Smith regularly meets with heads of state, and in 2023 played a key role at the World Economic Forum's Annual Meeting. Smith developed an international treaty called the Digital Geneva Convention to protect citizens against state-sponsored cyberattacks. Microsoft's Digital Diplomacy Group actively works on a tech-focused approach to foreign policy. The company sees corporate foreign policy as good business that builds trust and enables long-term planning. Meta,

Google, Amazon, Salesforce, and many other companies are now building teams centered on geopolitics and digital diplomacy. More than a dozen countries are creating ambassador-like positions charged to negotiate with the leaders of US Big Tech companies, with the aim of mediating disagreements, collaborating on shared interests and developing public-private alliances. The longer-term implications of corporations influencing global politics could be profound. What if a company's priorities differ from the national priorities of its home government?

National Security

While late to consider AI as a national security issue, the US is quickly playing catchup. The Pentagon is considering the creation of an extensive network that leverages AI along with drones and autonomous systems within the upcoming two years, aimed at mitigating threats posed by Russia, China and non-state actors. The White House has already initiated a multimillion-dollar cybersecurity competition aimed at encouraging the adoption of AI to identify and

repair vulnerabilities in the US government's infrastructure, responding to the increasing deployment of the technology by hackers for nefarious activities.

The Pentagon is considering plans to build an expansive network utilizing AI and drones over the next two years to address threats from Russia, China, and non-state groups.

Image credit: Future Today Institute and Midjourney.

WHAT IS CHINA DOING?

China is an undisputed global leader in AI. Under President Xi Jinping, the country has made tremendous strides in many fields, but especially in AI. Businesses and the government have collaborated on a sweeping plan to make China the world's primary AI innovation center by 2030, and it's making serious progress toward that goal. That plan is unlikely to be repealed by a new government; China abolished Xi's term limits and will effectively allow him to remain in power for life.

Within the next decade, China plans to meet two crucial milestones: By 2027, its People's Liberation Army will have a modern-ready force, and by 2030 the Chinese Communist Party (CCP) expects to have outpaced the US in AI and become the dominant force. China is producing what it calls "intelligentized" technologies to bolster both its economy and military.

Recently, China took major steps to shape the future of AI by releasing its own pretrained models, and it is forging ahead with its own natural language processing models, which makes sense since the most popular models in use now are trained on English text. China now has at least 130 LLMs, which accounts for 40% of the global total, closely trailing the US. Despite this rapid development, investors and analysts caution that many of these models lack sustainable business strategies, offer similar functionalities, and face rising operational expenses.

China's Expanding Market

It's a challenging time for Chinese startups because of rising tensions with the West. Companies hoping to gain traction in Europe are making efforts to cloak their origin. Shein, the e-commerce website popular among teens, says it was "founded in L.A.," but the company actually got its start in Nanjing and Guangzhou by relying on the region's manufacturing centers and ample supply chains. Or look at TikTok, which has said it's a US-based company—while the app's parent Chinese company ByteDance has employed linguistic gymnastics to separate itself. Binance, the world's largest crypto exchange, which was created in China, says that it doesn't have a headquarters located in one physical location.

It's no wonder that as Chinese startups hope to expand globally, they're seeking to distance themselves from the authoritarian regime in Beijing. But that creates political hurdles, especially as the CCP seeks to bring its home-grown technology ecosystem into lockstep with party leaders.

The result could be a future parallel universe, in which Chinese-created AI systems are shaped both by enormous amounts of data and local laws. In Brazil, a generative AI system might write an unfettered political essay in Portuguese about a leader––while in China, that same essay would be automatically filtered for politically sensitive words and phrases. As the CCP enforces new regulations targeting AI and what the government calls "deep synthesis tech," the ways in which people experience and work alongside AI could be dramatically different.

China's Big Tech

Alibaba, Tencent, and Baidu, which have made important advancements in AI research, may find it difficult to keep innovating. Starting in 2020, the CCP initiated a wave of legislation aimed at its tech sector, introducing anti-monopoly legislation focused on the platform economy and promoting data security and privacy laws. The Personal Information Protection Law (PIPL), China's version of the EU's GDPR, went into effect in 2021. What followed were a series of crackdowns targeting some of

WHAT IS CHINA DOING?

China's most successful tech companies. Ultimately, this regulation wasn't about "breaking up" China's Big Tech—the CCP wanted to focus its tech sector on achieving research and development goals set by the government and military within the decade.

Increasingly, Beijing is pressuring its mega-successful big tech companies to share data with the state and to perform research to support the vision of the CCP. Going forward, Beijing aims to direct the might of its tech companies at programs of national strategic importance rather than making video games. China's tech crackdown could cool private investment in Chinese companies, which could result in a chilling effect on innovation and economic growth, and also free up capital for emerging markets.

Deepening International Ties

China is actively building out AI infrastructure and ecosystems, specifically focused on developing nations. By focusing on the infrastructure and the ecosystem, Beijing is not just setting the stage—it's constructing the entire theater to establish Chinese-designed AI systems.

Over 140 cities globally, from Kuala Lumpur to Nairobi, are being transformed into "smart cities" and "safe cities" powered by AI. Chinese companies are providing the technology and expertise to supercharge aspects like transportation, logistics, and law enforcement. China already leads the world in exports of AI-enabled surveillance systems. China's "Luban workshop" initiative is another strategic move by China, offering vocational training globally that includes AI education. This has resulted in the creation of a workforce skilled in AI in various developing nations. China also created a "BRICS AI Study Group" to accelerate AI cooperation with other developing economies. Chinese tech companies even helped construct the premier AI company in the UAE. Additionally, China dominates the market for industrial robot installations, having surpassed Japan in 2013. The gap between China and other countries has only widened—in 2021, China installed more industrial robots than the rest of the world combined.

This strategy mirrors China's Belt and Road initiative but instead of building physical infrastructure in developing nations to increase influence, China is building the technological infrastructure, which includes skills and data flow. However, US export controls on key semiconductors and technologies to China present obstacles. In response, China has taken measures such as prohibiting the use of chips from American company Micron in its infrastructure and implementing a licensing system for the export of specific essential metals like gallium and germanium, which are crucial for high-end semiconductors as well as components in solar panels and electric vehicles.

As China shapes the world order in its own image, it is simultaneously exporting its technologies and surveillance systems to other countries with authoritarian regimes. When the CCP expands into African countries and throughout Southeast Asia and Latin America, it will also begin to eschew

China is funding smart cities powered by Chinese AI and surveillance technology in developing nations. The country is exporting advanced monitoring systems as part of a broader strategy to extend its technological and geopolitical influence.

Image credit: Future Today Institute and Midjourney.

WHAT IS CHINA DOING?

operating systems, technologies, and infrastructure built by the West. Two Chinese companies— the state-controlled CEIEC and Huawei—built Ecuador's surveillance system, called ECU-911. The system promised to curb high murder rates and drug crime, but Ecuador could not afford the investment. As a result, a deal was struck for a Chinese-built surveillance system financed with Chinese loans. It was a prelude to a much more lucrative deal: Ecuador eventually signed away big portions of its oil reserves to China to help finance infrastructure projects. Similar package deals have been brokered in Venezuela and Bolivia.

China is quietly weaponizing AI, too. China's People's Liberation Army is catching up to the US military, using AI for such tasks as spotting hidden images with drones. The Chinese military is equipping helicopters and jet fighters with AI. The government created a top-secret military lab—a Chinese version of DARPA—and it's building billion-dollar AI national laboratories. China's military is achieving remarkable AI successes, including

a recent test of "swarm intelligence" that can automate dozens of armed drones.

When it comes to AI, leaders should monitor escalating tensions between the US and China. But they should also remember that there are cells of rogue actors who could cripple our economies simply by mucking with the power or traffic grids, causing traffic spikes on the internet, or locking us out of our connected home appliances. These aren't big, obvious signs of aggression, and that is a problem for many countries, including the US. Most governments don't have a paradigm describing a constellation of aggressive actions. Each action on its own might be insignificant. What are the escalation triggers? Without a definition, a strategic vulnerability exists.

China is quickly advancing military applications of AI, recently demonstrating swarm intelligence capabilities to coordinate actions of dozens of armed drones.

Image credit: Future Today Institute and Midjourney.

WHAT IS EUROPE DOING?

In late 2023, The European Union finalized negotiations on its landmark AI Act. This legislation establishes the world's first comprehensive framework for regulating AI systems. The overarching goals are to guarantee AI safety, uphold ethical standards, and drive European AI leadership. Specifically, the EU AI Act classifies AI systems into different risk categories based on their use cases.

In February 2024, a new European AI Office, established within the European Commission, was announced to promote the development and use of safe and trustworthy AI across the EU, functioning as the core of a unified European AI governance system. Through the implementation of the AI Act, the office aims to safeguard health, safety, and fundamental rights, providing a stable legal environment for businesses in all 27 member states. It will be responsible for monitoring compliance and in enforcing AI regulations.

France aims to advance its AI capabilities and influence. President Macron promised more than $500 million to cultivate French AI "champions" and counter Silicon Valley's English-dominance in AI systems. Mistral, a Paris-based AI company founded by Arthur Mensch, Guillaume Lample, and Timothée Lacroix, former AI researchers at Meta and DeepMind, is gaining attention for its rapid growth and focus on developing smaller, high-performance AI models as an alternative to giants like OpenAI. Unlike some larger, more restrictive models, Mistral's offerings can run locally with open weights, allowing for more accessible and flexible use in multiple languages for various tasks, claiming to outperform or match other leading models on certain benchmarks. The company uses a novel mixture of experts (MoE) architecture, enhancing efficiency by routing tasks to specialized neural networks, making processing faster and less resource-intensive. Mistral made its models available for public use under the Apache 2.0 license via Hugging Face and BitTorrent—yes, the same BitTorrent that gained notoriety housing illegally copied movies and music and allowing downloads via its peer-to-peer network—and the company recently launched beta access to its API for different levels of Mistral models.

Germany also recognizes the geo-strategic importance of AI innovation to compete with American and Chinese tech giants. A new hub in the southeast city of Heilbronn aspires to be a startup epicenter applying AI to help German industrial leaders stay competitive. Germany has committed nearly 500 million euros toward AI research and innovation, aiming to enhance supercomputing infrastructure, skill development, and create 150 new professorships, with a focus on achieving "technological sovereignty" and reducing its dependency on external powers. German Federal Minister of Education and Research Bettina Stark-Watzinger is lobbying for EU-wide cooperation in AI, particularly between Germany, France, and Scandinavian countries, to position Europe at the forefront of the global AI landscape. Despite all these commitments, concerns linger about the slow

WHAT IS EUROPE DOING?

pace of integrating AI into the broader economy and the potential stifling effect of the EU's AI Act on innovation, highlighting the need for more effective transfer of research to practical applications and the creation of a robust AI-specific infrastructure.

Brexit continues to complicate Europe's AI landscape. The UK government, following a white paper it published in March 2023, decided against introducing new AI-specific legislation, opting instead for a pro-innovation regulatory framework that leverages existing regulatory powers to manage AI technologies. This approach emphasizes high-level principles such as safety, transparency, and fairness to guide regulators, without imposing statutory duties to ensure flexibility and adaptability in AI oversight. One area still

up for debate is intellectual property across news and entertainment media. The House of Lords have called for standardized regulatory powers and meaningful sanctions to deter wrongdoing––without explaining what oversight would need to entail, or how innovation can still be counted on to stimulate the UK economy.

Finally, let's not forget Russia, which seeks to counter Western dominance in AI. In November 2023, Russian President Vladimir Putin announced plans for the development of an AI national strategy, stressing that its focus would be to prevent Western monopoly. He criticized the "monopolistic dominance" of foreign technology in Russia as unacceptable and dangerous, highlighting that many AI systems are trained on Western data, reflecting

ethics and norms that the Kremlin opposes. Putin warned against the "digital cancellation" of traditional Russian culture by Western AI algorithms, which he claimed often exclude or ignore Russian contributions to culture, science, and literature. He pledged significant investment in supercomputers and other technologies to enhance national AI research, underscoring the need for AI developments to be grounded in Russian traditional values and cultural heritage.

Putin is justifiably worried about adopting a Western paradigm of AI. Models like ChatGPT are trained overwhelmingly in English and are likely to exhibit the same assumptions as English-language media that could contradict official narratives peddled by Russian media.

Major Russian tech companies like Yandex and Sberbank are racing to build their own rivals to ChatGPT. But their offerings already lag behind the accelerating innovation of US and Chinese tech giants. Western sanctions further hamper access to vital computing power. Perhaps most critically, Russia's authoritarian atmosphere of censorship and distrust conflicts with the very nature of imaginative, generative AI.

WHAT IS THE MIDDLE EAST DOING?

The United Arab Emirates is positioning itself as a neutral ground for the advancement of artificial intelligence, aiming to bridge the gap between the US and China amidst ongoing geopolitical tensions. To date, the UAE government has shown deft diplomatic skills in navigating complex international relations that increasingly involve AI and other critical technologies.

Though the UAE government has worked hard to remain neutral, its companies are still caught in the crosshairs between the ongoing race between the US and China for AI supremacy. A major innovator based in Abu Dhabi, G42, develops advanced technologies across sectors like space, health care, energy, and security, but in December 2023, it faced growing pressure to cut ties with

hardware suppliers such as Huawei. The decision to phase out Chinese hardware was also a move to preserve G42's access to US-made chips.

Also late in 2023, the government launched a new state-sponsored AI company, AI71, to commercialize its leading LLM, Falcon. AI71 aspires to directly compete with leading AI labs like OpenAI. The UAE is also focusing on nurturing its homegrown talent in AI by investing in specialized education. It established the Mohamed bin Zayed University of Artificial Intelligence (MBZUAI), recruiting renowned experts from institutions like University of California, Berkeley and Carnegie Mellon as its faculty. The university produces scores of graduates annually, most of whom work at local Emirati technology companies.

In parallel, the Kingdom of Saudi Arabia has embarked on its own sweeping economic diversification agenda centered around AI. Through its Vision 2030 plan, the kingdom seeks to position itself for a future where the global economy is less dependent on oil and more driven by technology and innovation. The crown jewel of Vision 2030 is Neom, a futuristic megacity under construction aiming to seamlessly integrate cutting-edge technologies like robotics and AI across all aspects of daily life.

The kingdom is backing its AI ambitions with significant investments, including $20 billion specifically earmarked for advancing artificial intelligence. It established the Saudi Data and Artificial Intelligence Authority (SDAIA) to drive the national

AI strategy. SDAIA initiatives like the National Center for Artificial Intelligence are designed to make Saudi Arabia an AI leader across priority industries such as health care. Global tech giants have taken note, with China's Huawei recently launching a new cloud data center in Riyadh to grow its digital offerings in the region. The facility will support AI applications and Arabic language models to power government services. Though Huawei's expansion may benefit Saudi AI progress in the near term, Washington is likely to view such collaborations with concern given its wider technology rivalry with China.

The governance structures in KSA and the UAE allow for swifter decision-making and implementation of technology strategies compared to democracies, where public opinion on
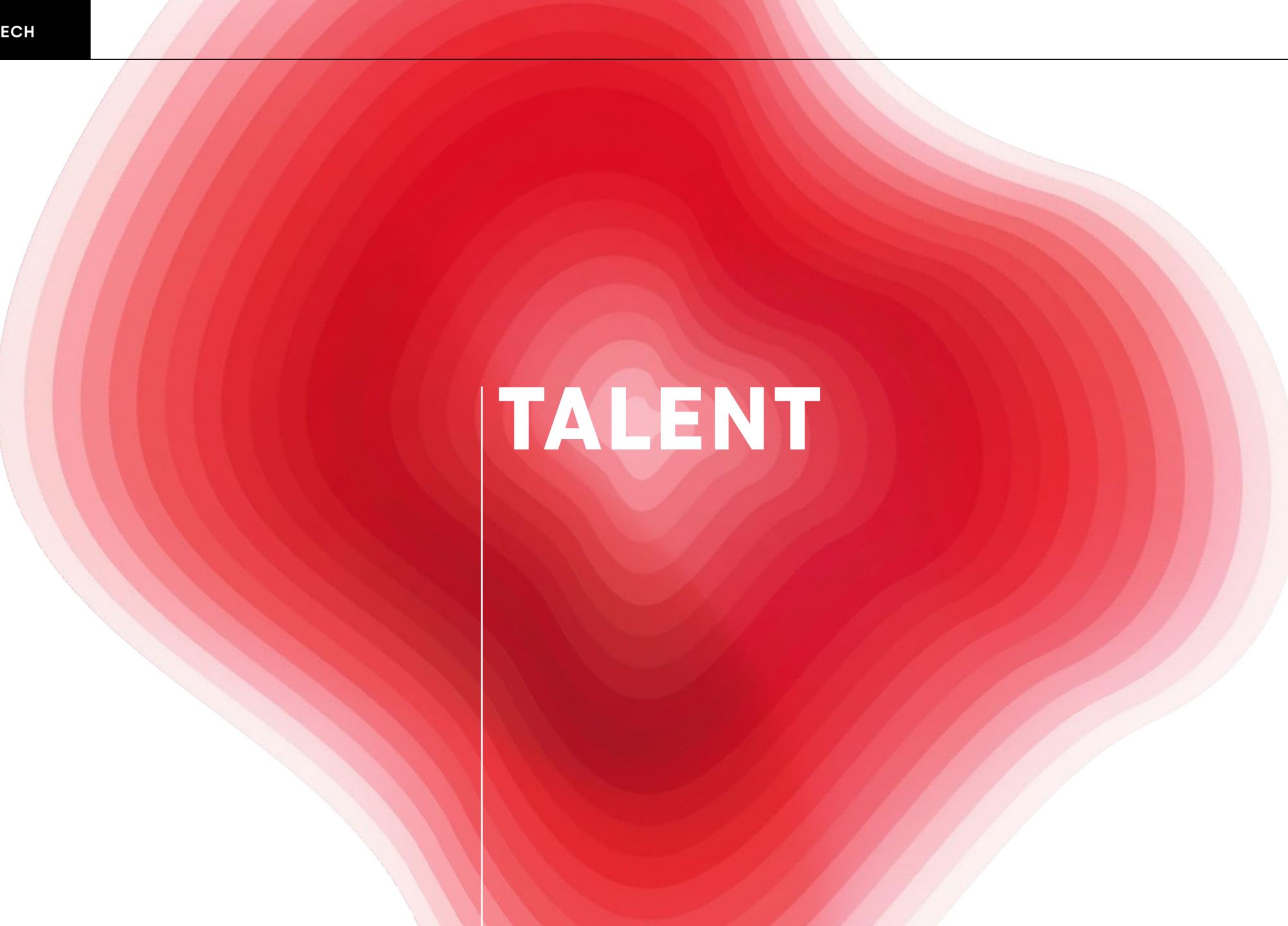
WHAT IS THE MIDDLE EAST DOING?

issues like privacy and employment significantly influences policy. These nations have the financial resources to invest heavily in essential AI components like GPUs, having spent hundreds of millions on them, as well as the energy required to power these intensive processors.

Many Middle Eastern nations are positioning themselves as emerging AI hubs, aggressively investing in AI skills development, research, and entrepreneurship. The goal is to diversify their economies in anticipation of declining reliance on oil.

Image credit: Future Today Institute and Midjourney.

TALENT

WHERE AND HOW DO I GET AI TALENT?

As AI permeates industries, demand has soared for technical talent to build and deploy AI capabilities. However, the rapid pace of innovation has yielded a global AI skills shortage. Employers struggle to attract talent, especially when competing against prestigious technology giants with deep pockets. This breeds uncertainty on optimal strategies, leading executives to wonder about the precise mix of skills needed in their workforce, whether current hiring approaches apply for burgeoning AI roles, and how to evaluate the technical caliber required for AI related work.

Demand for AI-related Skills Increases Across Sectors

Employer demand for AI skills is rising rapidly across nearly every industry in the US. With the exception of sectors such as agriculture, forestry, fishing, and hunting, there has been a noticeable uptick in AI-related job postings—from 1.7% of all postings in 2021 to 1.9% in 2022. Employers are actively seeking individuals proficient in machine learning, which tops the list of in-demand AI skills, followed by knowledge in artificial intelligence and natural language processing. The surge in these specific areas underscores a shift in the job market, with AI skill clusters achieving greater prominence than they had a decade prior. Demand for Python skills has also increased, evidence of its growing popularity as an AI coding language. This increased AI skills demand is not isolated to the US; it reflects a global trend. The US leads globally for AI-related job postings, followed by Canada and Spain. Furthermore, LinkedIn's AI skill penetration rate metric, which assesses the prevalence

of AI skills across occupations, has revealed that as of 2022, the regions leading in AI skill penetration are India, the United States, and Germany. The increasing prevalence of these skills points to a transformative phase in the job market, where AI proficiency is becoming a critical asset for professionals in a multitude of sectors.

AI Brain Drain from Academia

A striking shift has occurred in where AI Ph.D. graduates build their careers. The Artificial Intelligence Index Report from Stanford shows an increase in the proportion of AI Ph.D. graduates in North America entering the industry after graduation, from 44.4% in 2010 to roughly 48% in 2019, while the percentage taking up academic positions declined from 42.1% in 2010 to 23.7% in that same period. The reason is clear: Competitive salaries offered by the private sector, along with the chance to work on applied AI research, has tempted Ph.D.s away from the classroom to corporate America. Leading AI organizations, such as OpenAI and

Anthropic, are offering starting salaries for new researchers in the range of $700,000 to $900,000, according to salary negotiation service Rora, with Google even offering substantial restricted stock grants to attract top data scientists. That's orders of magnitude higher pay than what even tenured professors can expect from their universities. Top academics now earn generous corporate salaries and benefits, and they get to work in a similar tenured environment that's carefully cultivated to replicate their experience in academia.

Tech companies are also endowing AI professorships at top universities. In some cases, professors take one- or two-year sabbaticals to work at tech companies and then return to their universities. But corporate benefits can be difficult to give up, and companies need the talent. Poaching academia today could rob the future of future AI experts: Without great scholars, who will train the next generation of innovators?

HOW WILL AI CHANGE THE NATURE OF WORK?

In a clever study released last summer, researchers from the US demonstrated that shortly after ChatGPT was introduced, copywriters and graphic designers on prominent online freelancing sites experienced a notable decrease in job opportunities, along with steep declines in their earnings. Here's the rub: Generative AI wasn't only replacing their jobs, it was diminishing the value of the work they are trained to do.

It's become clear that AI will change how we do work, where we do work, and what work needs to be done in ways that are both piddling and profound. This breeds equal parts excitement and anxiety. While fears persist of mass job elimination, experts emphasize AI more as augmenting than replacing human roles—though the truth remains unclear. Furthermore, as AI becomes more sophisticated, able to collaborate with humans and demonstrate capabilities once considered uniquely human, it raises the question: Is AI a tool for workers to use or a colleague to collaborate with? The answer may determine how readily people embrace working with AI.

Gains and Pains

The integration of AI promises to both enhance efficiency for some roles while making other jobs more challenging. In the financial services sector, for instance, a study has highlighted how the integration of AI systems is increasing the demands on middle management. While AI applications efficiently handle routine tasks formerly executed by humans, this shift necessitates that managers adapt to new challenges and demands, navigating a landscape where they must balance traditional management roles with the oversight of AI systems.

Yet in medicine, AI is generally positioned as an empowering asset to augment clinicians rather than replace them. Physician-researchers at Beth Israel Deaconess Medical Center showed an AI chatbot surpassing human accuracy at probabilistic reasoning to aid diagnoses. Separately, scientists at University College London developed AI speech pattern detection tools to uncover early schizophrenia indicators. Rather than substituting the role of the physician, these technologies enable doctors to discern additional insights.

Status Shifts

Emerging research suggests AI may profoundly reshape perceptions of high-status occupations in the coming years by automating prestigious skills. Studies from the OECD and OpenAI forecast mass job losses even in respected professional domains like law, medicine, and finance. However, AI might also democratize skills that have long been associated with high-status roles. For instance, the use of AI like GPT-4 in professional services has shown that those leveraging these tools can outperform their peers across various tasks. LLMs might be just as good—or even better—at certain jobs in law firms because the work can be automated for faster, cheaper results. The use of LLMs in law could change how legal work is done, potentially reducing the need for junior lawyers for routine tasks and forcing legal process outsourcing firms to change their business models, while also offering law firms and legal departments significant efficiency gains and cost savings. This

HOW WILL AI CHANGE THE NATURE OF WORK?

suggests that AI has the potential to level the playing field, allowing individuals who might not have traditionally excelled in these roles to boost their performance and productivity.

This shift also brings a potential upheaval in the power dynamics traditionally associated with specialized skills and knowledge. High verbal intelligence, once a marker of elite status and a key to high earnings, might lose its prestige as AI begins to outperform humans in tasks involving language and writing. Skills such as writing proficiency or multilingualism, previously indicators of a highly educated individual, may diminish in value as AI improves text quality and eliminates language barriers.

The possible reduction in status and influence for those skilled in words and symbols is a significant cultural shift. For centuries, Western societies have revered those adept at conceiving and communicating new concepts. The rise of the Scientific and Industrial revolutions only amplified their status and influence. The encroachment of AI into these

realms could represent a profound and unprecedented shift in societal values and the stratification of labor. In this new era, jobs that are less susceptible to automation, such as skilled trades, might gain in prestige and economic reward relative to those more easily disrupted by AI technologies.

Agents Will Increasingly Perform Tasks on Our Behalf

The workforce is increasingly familiarizing itself with chatbots to perform routine tasks like drafting emails and synthesizing technical language and documents. AI agents would take this a step further by actively performing tasks like sending emails, scheduling meetings, and booking reservations. These agents represent a shift toward a more proactive and autonomous model, transcending the capabilities of traditional chatbots. AI agents could book your vacation, coordinate dinner reservations among friends' calendars, or perform specific tasks relevant to a particular role at a company. For example, a product owner AI agent could specialize in aiding with market analysis,

prioritizing features, and developing business cases. A developer AI agent would focus on automating code generation, refining existing code, and aiding in bug detection.

But these agents wouldn't be siloed to interaction with humans—they can interact with one another just as humans would to accomplish a goal. Imagine an ecosystem populated by specialized AI agents, each equipped with distinct expertise and knowledge, designed to not only assist individual tasks but also to collaborate and interact with one another. This vision points toward a future where AI agents evolve from performing singular, user-specific tasks— like drafting emails, resolving customer support queries, or managing grocery orders—to operating within a network where they communicate and cooperate with other agents.

Companies that possess extensive data repositories in specific verticals are likely to emerge as leaders in the AI Agent space. For example, Bloomberg, with its rich trove of financial data, is well-positioned to develop

sophisticated financial AI agents. It's already begun creating large language models tailored to finance. Similarly, LexisNexis, with its vast legal information database, could develop AI agents specialized in the legal domain. These AI agents, drawing from deep wells of domain-specific data, would not only cater to their direct users but also become invaluable assets to other businesses, systems, and AI agents.

EMERGING CAPABILITIES

CAN AI REASON? AND HOW CLOSE ARE WE REALLY TO AGI AND ASI?

Can AI think like a human? Recent advances suggest we may be close to unlocking AI's potential for complex reasoning, and perhaps even one day achieving artificial general intelligence (AGI), shorthand for a computer that can do anything a human brain can. Microsoft recently startled the AI community, becoming the first major tech company to argue current systems exhibit sparks of AGI. While it never made that same proclamation, Google's DeepMind team has repeatedly demonstrated nascent AGI capabilities in its research.

AGI refers to flexible, human-level cognition able to tackle any intellectual task. Yet progress has been uneven across the spectrum of what a human brain is able to do. Contrary to sci-fi visions of AI's prowess at logic and math, early breakthroughs in artificial intelligence were primarily in creative realms like art and language modeling. Initially, it was believed that AI would excel in reason-based jobs, particularly in mathematics, given computers' inherent proficiency in handling numbers and calculations at a speed far surpassing human capabilities. However, the evolution of AI has taken a somewhat unexpected turn, veering more towards creative applications rather than purely logical reasoning. That is, until now. Looking beyond AGI, the ultimate frontier is artificial super intelligence (ASI)—AI that surpasses human intelligence in every aspect, from creativity to problem-solving, heralding an era where AI's capabilities could transcend human limitations.

> "
>
> Will AI take over the world? No, this is a projection of human nature on machines.
>
> —Yann LeCun,
>   vice president and chief AI scientist at Meta

AI Breakthroughs in Mathematics

A breakthrough in AI's mathematical abilities was showcased by DeepMind's Alpha-Geometry. In a landmark paper published in Nature, AlphaGeometry demonstrated its capability to solve complex geometry problems at a level comparable to a human Olympiad gold medalist. It successfully solved 25 out of 30 Olympiad-level geometry problems within the standard time limit, a performance on par with top human competitors.

The success of AlphaGeometry highlights AI's growing capacity for logical reasoning and knowledge discovery. AlphaGeometry effectively showcases a process that mirrors real thinking. Its process has been compared to the dual-process theory of thinking, Type I and Type II, as popularized by psychologist Daniel Kahneman in "Thinking, Fast and Slow." Also from the DeepMind team, a technique involving LLMs named FunSearch has demonstrated that AI can assist mathematicians in solving wicked problems, inspired by the card game "Set." This marks the first instance where an LLM-based system has been able to surpass existing mathematical and computer science solutions, proving yet again that AI can solve a wide array of math and compsci questions more effectively than human mathematicians working alone. FunSearch works by generating and testing short computer programs for solving mathematical problems, refining its approach through feedback, and represents a novel form of human-machine collaboration that could amplify the capabilities of human mathematicians rather than replace them.

CAN AI REASON? AND HOW CLOSE ARE WE REALLY TO AGI AND ASI?

AI Persuasion

Logical argument is core to persuasion, but emotional resonance and validating existing views profoundly shape what people are convinced of too. AI shows promising aptitude on both fronts—generating seemingly rational arguments while precisely targeting psychological triggers. OpenAI CEO Sam Altman recently warned superhuman persuasiveness may arise in AI before general intelligence does, with unpredictable outcomes. AI chatbots, like OpenAI's ChatGPT, have demonstrated an impressive level of conversational prowess; they can sound convincing, even when providing incorrect information, which is particularly troubling when considering the human tendency to form emotional connections with these systems. Evidence shows even limited interactions with AI chatbots promotes attachment and trust, amplifying their capacity for conviction.

Researchers at Stanford's Polarization and Social Change Lab and the Institute for Human-Centered Artificial Intelligence conducted studies to explore AI's capabilities in swaying public opinion on contentious political issues. Their findings were alarming: AI-generated arguments were as persuasive, if not more so, than those penned by humans on a range of topics. For example, AI-crafted messages on policies like smoking bans and carbon taxes significantly shifted readers' support. While highlighting AI's influential potential, researchers in parallel sound alarms on misuse by hostile actors. As models continue absorbing the intricacies of human psychology while simultaneously continuing to improve at logic-based persuasion, safeguarding against deception emerges paramount.

Prediction and Prescience Into Our Human Lives

Will I die within four years? This is one of the questions that a collaborative research project is pushing AI to be able to answer. By leveraging large data sets detailing various aspects of people's lives and employing transformer models—similar to those underpinning the language processing capabilities of systems like ChatGPT—the researchers have developed methods for organizing this data to forecast future events in an individual's life. Notably, their model, dubbed Life-2vec, can make predictions about profoundly significant events, including estimating the time frame of a person's death.

The cutting edge in AI reveals accelerating abilities to computationally interpret integral aspects of the human experience—from life outcomes to subjective thought itself. Recent research has demonstrated AI's ability to not only forecast significant life events but also to delve into the depths of human cognition by reconstructing images seen by individuals, based solely on brain scans. A team from Osaka University in Japan has achieved a groundbreaking feat in cognitive AI. By analyzing functional magnetic resonance imaging (fMRI) scans taken while subjects viewed specific images, the AI system they trained was able to recreate these images with surprising accuracy. The AI generated visuals of a teddy bear, a clock tower, and an airplane, among other objects, after participants had looked at similar items. This research marks a significant step forward in AI's ability to interpret and visualize human thoughts based on neurological data. The implications of these advancements are profound. AI's ability to predict life events suggests a future where technology could offer insights into personal and societal trends with unprecedented accuracy. Meanwhile, the capacity to reconstruct visual experiences from brain scans opens new avenues for understanding human cognition, memory, and perception.

More practically, Nvidia is developing an AI-powered "digital twin" of Earth, known as Earth-2, leveraging its FourCastNet AI model to predict weather with unprecedented speed and accuracy, outperforming traditional methods by forecasting thousands of potential outcomes. This breakthrough in climate modeling represents a huge advance in applied research.

Detecting Emotion

A new type of neural network can determine how people are feeling. Using radio waves, AI can detect subtle changes in heart rhythms,

CAN AI REASON? AND HOW CLOSE ARE WE REALLY TO AGI AND ASI?

run a pattern analysis, and predict someone's emotional state in a given moment. A team from Queen Mary University of London used a transmitting radio antenna to bounce radio waves off test subjects and trained a neural net to detect fear, disgust, joy and relaxation, as people were shown different videos. The system accurately tagged emotional states 71% of the time, which signals new opportunities for health and wellness applications, as well as for job interviews and the government/military intelligence community. The EU is sponsoring a pilot project called iBorderCtrl that uses emotion recognition technology to assess truthfulness in border crossing interviews—the system analyzes interviewees' micro-expressions and nonverbal cues in an attempt to quantify the likelihood of deception during questioning. However, emotion recognition technology is still emerging and its accuracy in quantifying human emotion remains unproven, given the inherent complexity and nuance of human expression. Some of the most advanced emotion recognition technology is currently being developed in China, where extensive work has been done on facial

recognition systems, albeit amid ethical concerns over potential misuse—the country has faced scrutiny for employing emotion AI to enable surveillance, most notably to monitor the Uyghur population.

Neuro-symbolic AI

Neuro-symbolic AI combines the best of two worlds in AI: the learning capabilities of neural networks (which are good at handling unstructured data like images and language) and the reasoning capabilities of symbolic AI (which deals with structured data and logic). For businesses, this means they can create smarter systems that not only learn from vast amounts of data but also understand and apply rules and logic, similar to human reasoning. In practical terms, this means that a neuro-symbolic AI could analyze a company's data and also understand the context, making decisions that are more accurate and relevant to specific business scenarios. By understanding rules and logic, neuro-symbolic AI might automate tasks that previously required human understanding, saving time and reducing errors.

Amit Sheth, who founded the Artificial Intelligence Institute at the University of South Carolina, is exploring a new idea called neuro-symbolic vision. This approach is similar to how we, as humans, understand the world: by turning what we see and hear into symbols in our minds, and then using what we know to make sense of those symbols, make plans, and take actions. This way of processing information is also how we explain our thoughts and actions to others, which is especially important in areas like health care where trust is key. Neuro-symbolic AI aims to improve how smart systems figure things out and make them more accountable. By combining the learning power of neural networks with organized knowledge (like facts and rules), we could see big improvements in AI's ability to understand concepts, make connections, and reason about the world in a way that's clear to us. As people start questioning current AI methods, this neuro-symbolic approach could lead us toward creating AI that thinks more like humans do, which could be a big step toward achieving AGI.

AI can detect emotions through facial analysis and by tracking subtle biological clues like changing heart rhythms.

Image credit: Future Today Institute and Midjourney.

IS THE FUTURE OF AI CLOUD, EDGE, OR ON-DEVICE?

Where we will ultimately deploy AI workloads remains an open question. Many anticipate the future is likely to embrace a hybrid approach that combines cloud, edge, and on-device computing in some capacity. This strategy allows for data processing and model training to leverage the vast parallel processing power of cloud servers. Meanwhile, edge hardware and local devices could handle real-time inferences and personalization, optimizing for both performance and privacy. But the specific balance across environments and when to favor one over the other is still unclear as capabilities and demands evolve.

Cloud Neutrality

A handful of companies control the cloud and have the ability to set pricing, access and standards. Those companies own the infrastructure and don't have to make their business practices transparent. Generative AI systems require enormous amounts of costly computing power and cloud infrastructure, which the tech giants are trading for future shares of profit. This consolidates additional power among the largest cloud providers. As more of our businesses and aspects of our lives move to the cloud, efforts will grow to ensure that infrastructure serves the public interest. The three biggest cloud providers, Microsoft, Amazon, and Google, have collectively invested tens of billions of dollars building infrastructure: data centers, monitoring systems and software. Their robustly designed systems prevent downtime and data loss, and few other companies in the world can compete. But the cloud isn't public infrastructure; it's private. And as private companies, cloud providers currently control access to services that are becoming the lifeblood of businesses.

Cloud Strain From AI Boom

AI has arrived, but the underpinnings of the cloud may struggle to withstand its weight. Cloud providers such as Amazon Web Services, Microsoft Azure, and Google Cloud are under intense pressure to adapt their services to accommodate the needs of large-scale generative AI models, which can be up to 100 times larger than their predecessors. Generative AI models like ChatGPT that produce original text and analysis can be 10 to 100 times more complex than a Google search. The current cloud infrastructure, primarily designed to provide scalable, pay-as-you-go services for diverse workloads through general-purpose computing, is now significantly challenged by the demands of AI-intensive workloads.

Only a small portion of current cloud servers are outfitted with AI-optimized GPUs or structured to function in collaborative clusters, essential for meeting the substantial computational requirements of AI tasks. A significant bottleneck also arises from the scarce availability of high-performing GPUs, with Nvidia essentially serving as the sole supplier. Because of high demand, Nvidia's H100 graphics—an earlier version of their most powerful graphics—sold for more than $40,000 on eBay. To reduce their dependence on Nvidia, companies like Alphabet, Microsoft, and Amazon are developing their own AI chips for model training. Despite their cloud platforms not being fully optimized for AI, AI workloads are contributing to significant revenue growth in their cloud infrastructure.

AI Breathes Life Into Legacy Systems

The rising costs associated with cloud computing, especially for tasks like training AI models, are prompting some companies to reconsider on-premises solutions. Dell Technologies, recognizing this shift, has developed servers specifically designed for on-premises AI deployments. By moving AI operations in-house, Dell argues that companies can potentially save on networking and data storage expenses. Furthermore, AI is playing a pivotal role in revitalizing legacy mainframe systems. Over 800 billion lines of COBOL code are currently in use within production systems,

IS THE FUTURE OF AI CLOUD, EDGE, OR ON-DEVICE?

making the transition from this language, established in 1959, to more contemporary languages a daunting task. The scarcity of COBOL experts—many are nearing retirement age—and the complex nature of migration efforts for large organizations further compound these challenges. IBM's introduction of Code Assistant for IBM Z, an AI-powered tool that translates COBOL code into Java, offers a solution to modernize mainframe applications with the help of AI. This blend of AI innovation not only supports the shift towards on-premises AI deployments to manage costs but also demonstrates the potential for AI to breathe new life into legacy infrastructures.

Optimizing AI to Run at the Edge

Smart devices like phones lack the memory and computing power required to fine-tune AI models with user data over time. This limitation has necessitated transmitting personal information to the cloud for updating, an energy-intensive process that risks data privacy. Now, advances like PockEngine enable efficient on-device learning without offloading data. Developed through an MIT

and IBM collaboration, PockEngine is a training model that selectively identifies which specific parts of an otherwise enormous model to update locally based on a user's unique inputs. By focusing only on essential parameters and shifting computations to preprocessing, PockEngine minimizes real-time resource usage. Not only does this make it more efficient, it also facilitates the creation of personalized deep-learning models. For instance, AI assistants can continuously adapt to a user's accent or typing patterns without reliance on constant cloud connectivity. Tests demonstrate PockEngine fine-tuning complex models up to 15x faster than alternatives, all while maintaining or boosting accuracy.

Small Language Models for AI at the Edge

While large language models with billions or trillions of parameters have demonstrated impressive capabilities, smaller AI models may be better suited for edge-based use cases. Though less broadly capable, specialized mini-models bring benefits like faster inference, lower compute requirements, and

easier integration into edge devices. For mobile and embedded use cases, massive cloud-based LLMs are often impractical. Their substantial size and latency makes local deployment a non-starter. More compact models in the millions or single-digit billions of parameters, however, could potentially run efficiently on smartphones and IoT devices. Your washing machine could be equipped with a compact language model, enabling you to inform it verbally that you're washing a mixed load and are concerned about a sweater washing in overly warm water. The small language model that can run in the appliance eliminates the need for internet connectivity to operate your washing machine in this manner. SLMs could therefore empower voice assistants, smart home automation, and beyond, reducing the dependency on cloud-based services for these types of applications.

On-Device AI

Tech giants such as Samsung, Microsoft, Google, and Apple are spearheading a movement towards on-device AI, emphasizing a

blend of performance and privacy. These companies are competitively equipping their devices with specialized AI chips to enable local processing, thereby reducing reliance on cloud servers. This approach to on-device AI processing is motivated by the goal of safeguarding sensitive data, drastically cutting down the risk of data breaches during its transfer to and from the cloud. Moreover, on-device AI has the unique capability to adapt and personalize according to a user's behavior directly on the device. Samsung introduced its Galaxy S24 smartphones, showcasing a leap in AI capabilities with the implementation of generative AI tools that operate through a combination of on-device processing and cloud-based computations. Google's latest Pixel phone features custom AI silicon to handle tasks like predictive typing more responsively on-device. Apple's newest MacBook CPU incorporates neural processing units for faster machine learning. AMD's latest Ryzen mobile chips similarly target laptop enhancements like voice assistance.
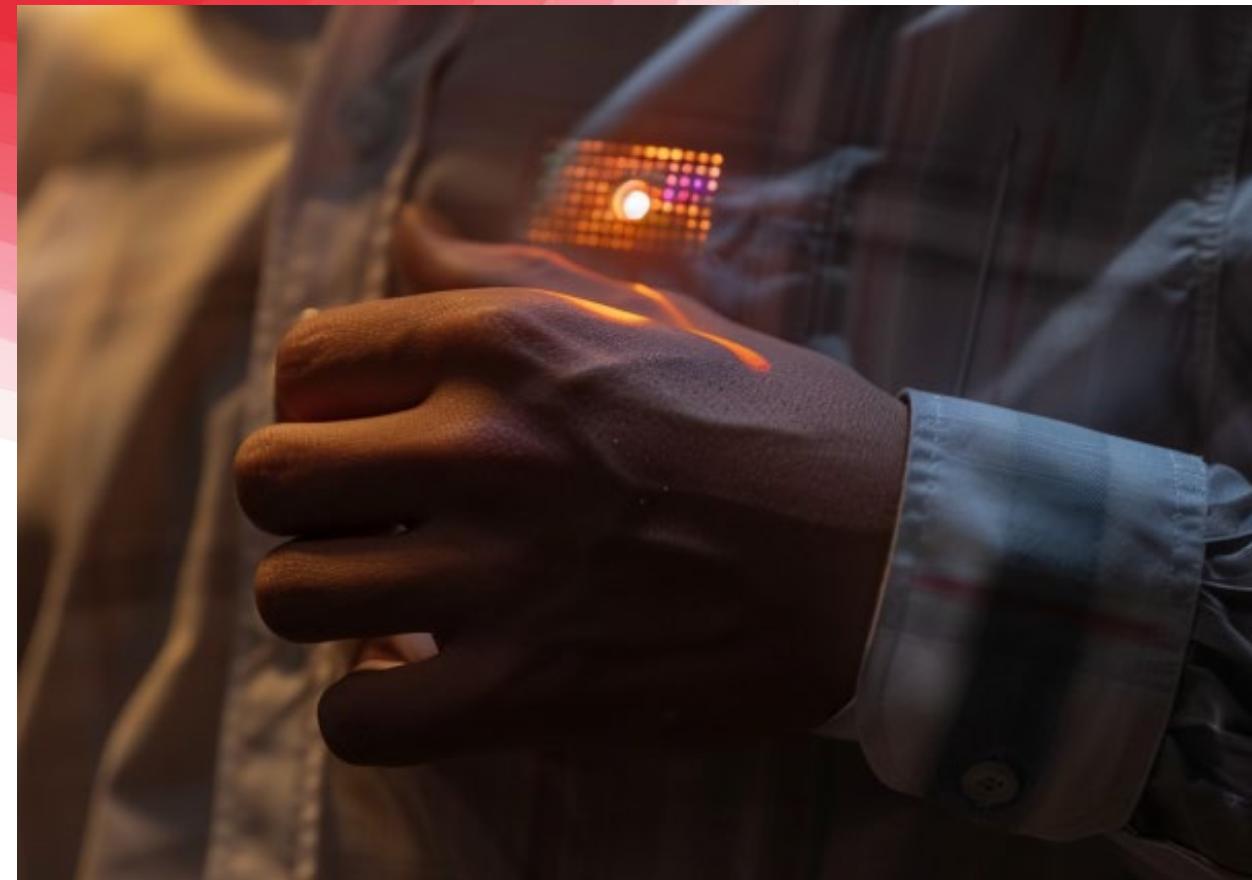
IS THE FUTURE OF AI CLOUD, EDGE, OR ON-DEVICE?

Wearable AI

AI is changing human-computer interaction, shifting us away from screens, track-pads, and keyboards towards more intuitive, voice-based interfaces. This is giving rise to a new class of lightweight, wearable gadgets and screenless computers that integrate seamlessly into daily life. By reducing screen fatigue and intrusive features, these devices foster a more natural, human-centric approach to technology. A prime example is the newly launched Humane AI Pin, an OpenAI-powered wearable priced at $699, plus a $24 monthly subscription. Forgoing traditional app interfaces, this 34-gram device focuses solely on voice interactions. Users access information and perform tasks by speaking to the Pin's built-in microphone. By stripping down the technological interface, Humane aims to create a streamlined, human-like experience. Another device is the Rewind AI Pendant, which captures real-world conversations, storing encrypted transcripts and audio locally on the user's phone. Beyond recording, Rewind's platform searches transcripts, generates meeting summaries

and analyzes speech patterns. Essentially, the Pendant serves as a personalized assistant harnessing environmental information to support the user. Both the Humane Pin and Rewind Pendant epitomize the shift towards invisible, assistive technology that facilitates life's tasks and interactions much like a helpful human companion would. This evolution in form and function represents a paradigm shift, integrating technology more seamlessly while making it feel more intuitive and human-centric.

Note: we've included this trend in both the AI and Computing reports. We think it is important to consider the near-future of wearables as you contemplate the future of your organization and AI's development.

AI can let us get information by voice requests rather than typing search terms or looking through folders. This more natural interaction could drive demand for wearable or voice-based interfaces.

Image credit: Future Today Institute and Midjourney.

WHY SHOULD WE PAY ATTENTION TO EMERGING CAPABILITIES THAT AREN'T YET FULLY DEVELOPED?

Businesses should keep an eye on emerging AI capabilities because these technologies can unlock new opportunities for innovation, efficiency, and competitive advantage. Early awareness and adoption of AI advancements can position a company as a market leader, enabling it to refine its operations, enhance customer experiences, and create novel products or services.

Vector Databases

Vector databases are poised to grow rapidly in importance alongside advancements in AI. As AI models like large language models become more capable of human-like generation across modalities like text, images, and audio, they rely heavily on vector representations of data, known as embeddings, to understand and generate contextual meaning. To function optimally, these generative models need databases specifically designed to store massive vector data sets and allow instantaneous retrieval of semantically similar vectors. This is where vector databases come in; they are uniquely designed to efficiently store, manage, and retrieve high-dimensional vector data, which is crucial for embedding processes found in natural language processing, image generation, and other AI applications. Unlike traditional databases that organize data in rows and columns, vector databases use vectors to represent data points, enabling faster and more relevant data retrieval based on similarity. As companies like Microsoft and Oracle introduce vector databases into their product offerings, and funding flows into vector database startups, adoption will accelerate. By 2026, over 30% of enterprises are expected to implement vector databases to support their AI models. This trend signals a skills shift as well, with data and software engineering teams needing more knowledge of techniques like semantic search and vector indexes to successfully leverage vector databases for AI use cases.

Vertical Integration From Hardware to LLMs

Companies are increasingly adopting a holistic approach to AI development, seeking to dominate the entire spectrum from hardware to LLMs through end-to-end vertical integration. This strategy would allow companies to oversee the full pipeline, from the foundational hardware to the sophisticated AI models that drive innovation. Nvidia, a titan in the realm of AI hardware, is now speculated to potentially broaden its scope into cloud computing services. By capitalizing on its hardware prowess, Nvidia could offer comprehensive AI cloud services, further cementing its role in shaping the AI domain.

If you aren't ahead, you are already behind. Proactively assessing how innovations apply to their operations and offerings will help companies capitalize on advances and stay competitive.

Image credit: Future Today Institute and Midjourney.
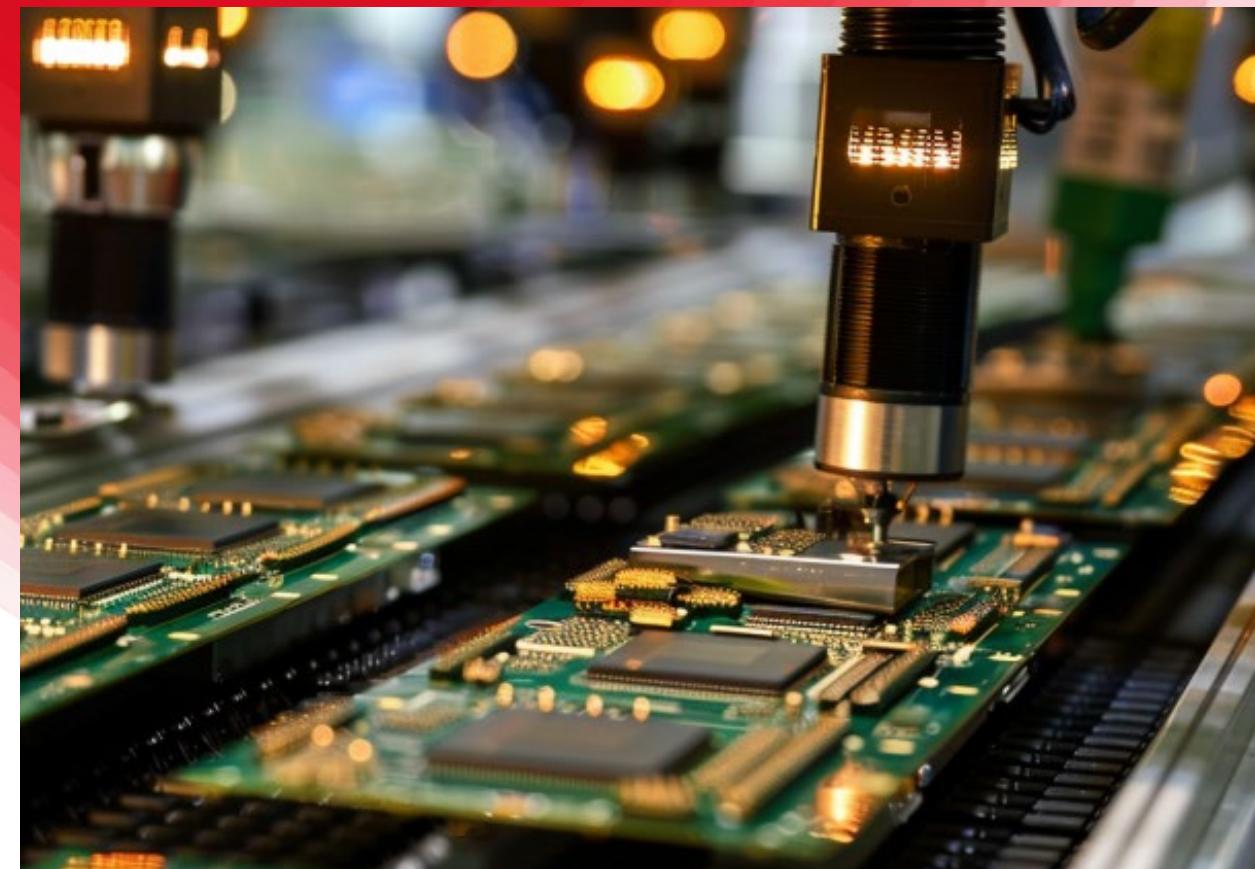
WHY SHOULD WE PAY ATTENTION TO EMERGING CAPABILITIES THAT AREN'T YET FULLY DEVELOPED?

Nvidia's GeForce Now, a cloud streaming service, already demonstrates the company's capability to merge high-performance hardware with cloud-based offerings, hinting at a future where Nvidia's influence extends across the AI ecosystem. In February 2024, Nvidia demoed a personalized AI chatbot for Windows PCs that connects to local files, enabling natural language queries such as "what restaurant did my friend recommend?". Rather than searching manually, users can query the chatbot directly to retrieve information from personal notes and messages.

Meanwhile, cloud AI providers like Amazon, along with emerging AI startups like Anthropic and Mistral, currently depend on third-party hardware for their AI operations. This dependency poses the question of whether these entities might emulate OpenAI's strategy of procuring their own chips. In early 2024, Sam Altman, OpenAI CEO, indicated that he plans to raise billions for an AI chip venture aimed at developing a network of factories for fabrication. Intel's foray into AI software development further illustrates this trend. Leveraging

one of its supercomputers, Intel has built a generative AI system capable of processing text and images. This initiative not only showcases Intel's commitment to advancing AI capabilities but also emphasizes the strategic value of controlling both hardware and software components in delivering sophisticated, secure, and efficient AI solutions.

Companies are now adopting a comprehensive strategy for AI, covering everything from hardware to LLMs. They aim for control over the entire AI development process through vertical integration.

Image credit: Future Today Institute and Midjourney.

INDUSTRIES

INDUSTRIES

Many companies have new competitors—they just don't realize it yet. The boundaries between sectors are blurring; professional services firms traditionally known for consulting are now venturing into engineering, powered by AI technologies. Similarly, big tech hyperscalers, once primarily focused on building and hosting tech infrastructure, are expanding into consulting services. This crossover signifies that AI's versatility and capability to add value across different functions are enabling companies to enter and compete in domains previously beyond their reach. Consequently, businesses may find themselves up against competitors from entirely different industries, underscoring the need to innovate and adapt strategies in response to the unpredictable dynamics AI introduces to the market.

While AI may not directly replace every job, it positions those who embrace its capabilities to outperform and replace those who do not.

Image credit: Future Today Institute and Midjourney.

HOW IS AI BEING USED IN HR?

AI is enabling HR departments to automate time-consuming administrative tasks like screening job applicants, while also providing insights to enhance employee retention, training, development and engagement. From personalized onboarding chatbots to performance comparison analytics, companies are unleashing AI to expedite recruiting, predict attrition risk, optimize benefits, identify productivity barriers and mitigate bias in reviews. Though valid ethical concerns remain, AI has significant potential in HR to both improve experiences for employees and drive better overall business performance.

Autonomous Talent Acquisition

AI automation can significantly reduce the time and cost of recruiting by handling tedious, manual tasks like screening resumes, scheduling interviews, and tailoring outreach. Johnson & Johnson leveraged AI writing tools to reduce unconscious bias in job descriptions, improving gender diversity in applicants. AI also assists with onboarding tasks like verifying employee paperwork, delivering induction training, and providing system access. By automating repetitive HR workflows, AI allows recruiters and managers to focus their human skills on building relationships and strategic planning. Overall, AI promises major gains in operational efficiency, cost savings, and unbiased, personalized experiences for both recruiting and onboarding processes.

Customer and Personnel Recognition Systems

Recognition systems can now be deployed to watch people in an interview and gauge enthusiasm, tenacity, and poise. Algorithms analyze hundreds of details, such as the tone of voice, facial expressions, and mannerisms to best predict how a candidate will fit in with the culture of a community. Start-ups such as HireVue use AI systems to help companies decide which candidates to hire.

But this kind of recognition technology has practical applications beyond job interviews: It can detect when someone is likely to make a purchase—or attempt to shoplift—in a store, whether someone is lying, and whether someone is receptive to new suggestions and ideas. Unlike security cameras, which tend to have a light indicating they're recording, algorithms work invisibly, which means that this is an area that could face regulatory scrutiny. The consumer advocacy organization Electronic Privacy Information Center filed a complaint with the FTC requesting an investigation into HireVue, alleging its tools produce results that are "biased, unprovable, and not replicable" through algorithmic models.

Benefits Selection and Management

AI automation is taking over the complex tasks of managing employee benefits, including facilitating open enrollment, tracking individual coverage, and making adjustments due to life changes. This simplifies workflows for HR teams and provides employees smoother, more reliable experiences with their benefits. Startups like Paidleave.ai offer AI chatbots to assist workers in understanding and utilizing paid leave benefits. Major HR systems providers like ADP are also releasing AI assistants, such as ADP Assist, to help HR managers handle common inquiries and provide data-driven insights. By automating benefits administration, AI enables HR staff to focus on more strategic tasks while empowering employees through intuitive self-service tools.

HOW IS AI BEING USED IN MARKETING?

AI will change marketing in big ways. Algorithms can study lots of customer data to understand what people want. This lets marketers create very tailored ads and content for each person. AI chatbots can also have friendly conversations to help customers. Perhaps more importantly, AI shifts how buyers find and choose products in the first place. By changing the platforms people use, their behaviors change too. Marketers should fully rethink strategy as AI transforms what makes people discover and buy things.

AI Shifts Search

Early data signals that the rise of AI tools like ChatGPT may be subtly reducing Google search volumes. While the search giant still dominates with over 90% market share, metrics show marginal declines coinciding with surging interest in conversational AI. Rather than competitors like Bing stealing share, this hints at a more fundamental shift—people using search less because AI applications can directly provide information. For marketers who have invested heavily in search engine optimization, this presents a seismic challenge. If traffic from search shrinks in favor of on-device intelligent assistants, prevailing strategies get disrupted. The expected launch of AI models from Apple, Google, and others threaten an even greater paradigm change toward integrated, device-based discovery rather than browser-led journeys. In essence, where and how people find products appears poised for disruption. Marketers must prepare for an upcoming inflection point where search-centric models cede ground to AI-powered, omnipresent product discovery and recommen-

dation woven into the consumer experience. Failure to adapt approaches could prove highly risky in the coming years.

Dynamic Engagement Through Deep Personalization

Traditional marketing communications like emails, PDFs, and social posts have been static and one-way, but AI is ushering in a new era of responsive, conversational messaging. Chatbots and virtual influencers allow for personalized interactions where content changes based on the user. For example, Meta leverages AI characters based on celebrities like Snoop Dogg and Kendall Jenner to engage audiences through gaming and advice. While not real people, these bots represent AI's ability to gather data and connect with users in a more humanized, tailored way. As this technology advances, marketers can leverage AI to deliver deeply customized content that dynamically adapts to individuals' preferences and behaviors in real time. This interactivity creates more meaningful engagement between brands and consumers.

AI-Assisted Campaigns

Major digital advertising platforms like Meta and Google are unveiling new generative AI capabilities to assist advertisers in streamlining campaign creation. In May 2023, Meta launched AI Sandbox—a "playground" for testing AI-powered ad tools. Features include intelligent text variation to auto-generate messages optimized for different audiences, background image generation from text prompts, and image resizing to fit multiple social media formats. Meanwhile, Google expanded its Gemini conversational AI that creates full search campaigns from a single landing page URL provided by the advertiser. After some human tuning, Gemini's chatbot can collaborate with advertisers on campaign objectives, target segments, and ideas for extra ad content. These tools automate tedious creative tasks, allowing advertisers to instantly produce customized images, text, and even full campaigns tailored to their goals. And generative AI abilities like text-to-image, text-to-video, and text optimization further accelerate campaign ideation and production.

HOW IS AI BEING USED IN MARKETING?

Anecdotal Observations, Now Usable Marketing Data

Until recently, subtle human interactions and reactions, like micro-expressions, were merely anecdotal insights. However, advancements in AI now allow us to quantify these observations and transform them into quantifiable marketing data. Companies like Chooch use Vision AI to efficiently search video data and discern facial cues to understand consumer engagement. In physical stores, similar technology can monitor customer responsiveness to branding. Essentially, AI can convert once subjective perceptions into hard analytics to better personalize experiences. However, while this data enables deeper personalization, ethical questions remain regarding consent and privacy when collecting such intimate human insights. As the technology progresses, regulations and corporate responsibility practices must also evolve to protect and respect consumers.

Companies must strike a balance between responsibly using consumer data to provide personalized offerings while avoiding intrusive tracking that could undermine customer trust.

Image credit: Future Today Institute and Midjourney.
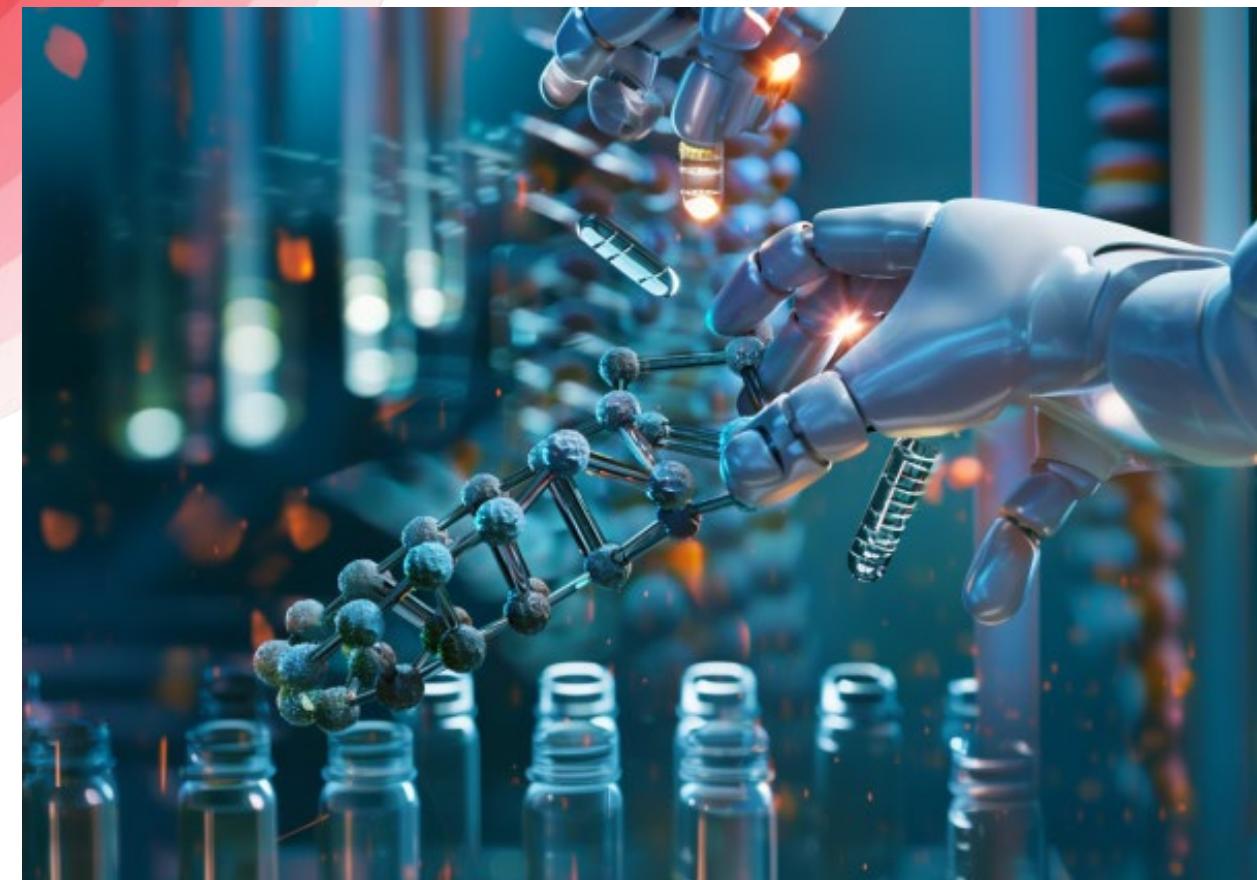
HOW IS AI BEING USED IN PHARMA?

With a history stretching back to the 1960s as one of the earliest adopters of computer technology, the pharmaceutical industry is now rapidly integrating AI into drug discovery. By applying advanced algorithms to harness vast data sets—from genomics to clinical trials—AI enables more targeted identification of promising candidates and illuminates their interactions with disease pathways. This streamlines the overall R&D process, heightening productivity and success rates while lowering costs. The acceleration and efficiency afforded by AI promises to expand treatment options for previously untreatable diseases. The gap between data-intensive computational labs and traditional wet labs is closing, with AI-designed molecules already advancing to clinical trials.

In short, the long-developing foundation of computing in pharma is now bearing fruit in the form of transformative AI applications spanning candidate screening to preclinical validation—reshaping how medications are researched and brought to market.

For deeper insights in how AI is being used in pharmaceuticals and life sciences, see the Bioengineering report.

AlphaFold has now predicted the 3D shapes of almost all proteins in the human body, accomplishing in just a few years what would have previously taken decades - or may have been impossible.

Image credit: Future Today Institute and Midjourney.

HOW IS AI BEING USED IN PHARMA?

Protein Folding

In 2020, DeepMind's AI made a big announcement: It had solved a 50-year grand challenge with AlphaFold, an AI tool that predicts the structure of proteins. AlphaFold outperformed an estimated 100 teams in a biennial protein-structure prediction challenge called Critical Assessment of Structure Prediction, a problem that has long vexed biologists.

AlphaFold had previously bested other teams but worked so quickly and so accurately that it signaled a near future when the technology could be used regularly by other scientists. Along with the newest version of AlphaFold, DeepMind published full details of the system and released its source code. It also made a stunning reveal: AlphaFold 2 has predicted the shapes of nearly every protein in the human body, as well as hundreds of thousands of other proteins found in 20 of the most widely studied organisms, including yeast, fruit flies, and mice. In a December 2023 update, Isomorphic Labs and DeepMind released an improved AlphaFold model that predicts protein structures with greater accuracy and

expands coverage to model interactions with additional molecules like ligands. By enhancing AlphaFold's capabilities, this latest iteration provides scientists a more powerful tool to rapidly examine proteins and molecular interactions for advancing fundamental biology research and applications.

AI-First Drug Development

The COVID-19 pandemic sparked a surge in AI applications for expediting drug discovery. An international research team demonstrated this potential by crowdsourcing an antiviral drug candidate in just 48 hours—a process that traditionally takes months. Separately, scientists at Ludwig-Maximilians-Universität München developed an AI model predicting where molecules can be chemically altered. By reducing required experiments, this enables more efficient, sustainable synthesis. Another University of Cambridge team created a platform that automates experiments, then uses AI to forecast chemical reactions. Until recently, this was a trial-and-error process—which means that it was slow and inefficient.

These examples reflect only a sample of the expansive AI drug discovery efforts underway across academia and industry. Major pharmaceutical leaders such as Johnson & Johnson, Novartis, and AstraZeneca have already forged partnerships with AI startups. The allure lies in deep learning's unmatched speed and pattern recognition capabilities for parsing volumes of data. While AI cannot wholly replace lab science (yet), it significantly accelerates prediction, design, and validation to streamline timelines.

Generative Antibody Design

An antibody is simply a protein that protects an organism. Produced by the immune system, antibodies bind to unwanted substances and eliminate them. In 2023, researchers from Absci Corp. showed how a generative AI model was able to design multiple novel antibodies that bind to a target receptor, HER2, more tightly than previously known therapeutic antibodies. What's interesting about this work is that researchers first removed all reference data on antibodies, so that the system couldn't just imitate and replicate the

structure of known antibodies that work well.

The designs produced by Absci's system were both diverse (meaning, they didn't have counterparts known to already exist) and they received a high score on "naturalness," so they would be easy to develop and therefore catalyze a strong immune response. Using generative AI to design novel antibodies that function at the same level––or even better––than those designed by our own bodies marks a bold new step in using AI to reduce the speed and cost of therapeutic antibody development.

HOW IS AI BEING USED IN HEALTH CARE?

The health care industry suffers from ballooning expenses and inadequate human resourcing. As the COVID-19 pandemic spotlighted, doctor and nurse shortages constrain delivery capacity even in times of immense need. AI could help make healthcare cheaper, easier to access, and higher quality by automating routine tasks. AI has demonstrated the ability to analyze certain types of test results as accurately as physicians, and faster. However, regulatory hurdles delay rollout of this technology. Safety regulations developed for a human-centered system now hinder AI adoption. Updating policies to allow ethical AI use, while still protecting patients, would facilitate major progress.

AI to Improve Patient Outcomes

AI can enable quicker, more accurate diagnosis and treatment, driving better patient outcomes. This impact is clear in managing critical conditions like sepsis. Saint Luke's Health System implemented an AI sepsis detection system, cutting the time to antibiotic administration by 32%. It also reduced sepsis deaths by 16%. Since sepsis accounts for one in three hospital deaths nationwide, early AI detection and treatment could save many lives. For example, UCHealth's AI tool is estimated to save around 375 lives yearly, and many more once it's rolled out.

Beyond the hospital, AI also helps patients better self-manage chronic diseases. Up to 70% make medication errors like incorrect insulin doses. But AI tools quietly identify these errors at home, nudging patients with alerts to take their treatments properly. Ensuring adherence promotes better outcomes. Additionally, poor communication frustrates 83% of patients. By enabling natural language processing and speech recognition, AI can facilitate more meaningful dialogues between doctors and patients. This clarifies therapeutic options and care decisions. In essence, AI boosts speed, accuracy, critical care, self-care, and communication in health care—all central to improving patient health.

AI-Assisted Diagnosis and Clinical Decision-Making

People have long turned to search engines to self-diagnose, but the emergence of AI chatbots like ChatGPT and Bing introduces a new era of medical consultation. LLMs have already demonstrated the ability to accurately provide potential diagnoses based on symptom descriptions, achieving an 88% accuracy rate in identifying the correct diagnosis among the top three choices, compared to a 96% accuracy rate by physicians given the same information. By processing natural language descriptions, chatbots empower more user-friendly symptom investigation compared to rigid online symptom checkers.

Beyond advising patients, AI also increasingly assists clinician decisions. FDA-approved systems already analyze imaging scans to detect abnormalities, leveraging data from billions of procedures. Algorithms likewise forecast patient risk levels by assessing extensive health records, outperforming conventional clinical scores. As demonstrated in a Beth Israel Deaconess Medical Center study, an AI chatbot even surpassed physicians in diagnostic accuracy for negative test results—highlighting potential to close certain cognition gaps. However, risks around reliance on potentially misinforming training data remain. If these can be addressed responsibly, AI has immense capacity to streamline radiology, reduce errors, aid predictions, and make consultation and reasons more accessible.

Anomaly Detection in Medical Imaging

Anomaly detection uses AI to detect abnormalities in medical images, helping clinicians identify issues faster. Machine learning algorithms have the capability to sift through extensive medical data, including imaging and pathology reports, significantly faster than humans working alone. In radiology, AI's ability to pinpoint anomalies in medical images is exceptionally accurate. Such early detection

HOW IS AI BEING USED IN HEALTH CARE?

significantly enhances patient outcomes for conditions such as cancer, leading to reduced mortality rates. For example, UC Davis Health has implemented Viz.ai, utilizing AI to analyze CT scans and flag potential strokes. Even though physicians still review all scans, the AI rapidly identifies anomalies to prioritize cases. Adoption of these AI tools is increasing, as 2021 FDA approvals now allow integration into standard workflows rather than just augmentation. IDx-DR uses AI to diagnose diabetic retinopathy from retinal scans, while Caption Health captures cardiac ultrasounds that nurses can interpret quickly with just a few days of AI software training.

Concerned about AI replacing doctors? There is already a critical shortage of physicians in rural areas. While AI can't take the place of physicians, it can simplify their workload especially when it comes to medical imaging, which could help to decrease the rate of burnout, and enable them to dedicate more attention to patient care. Though human review remains vital, these emerging autonomous systems prove the growing role AI plays in surfacing hard-to-spot anomalies in imaging.

AI-powered movement

Groundbreaking medical research uses brain implants and artificial intelligence to give paralyzed patients control over their bodies again. In early research, a quadriplegic patient can now move his arms and hands simply by thinking about the action. This is achieved through innovative neural bypass surgery, pioneered by scientists at Northwell Health. Microchips are embedded in the brain in the regions that control movement and sensation. Sophisticated AI algorithms then interface with the chips, interpreting the patient's thought patterns and translating desired actions into movement signals.

In a similar study, another patient regained control over his lower body with a spinal cord implant that bypasses injury sites. Termed a "digital bridge," an AI thought decoder reads his brain signals related to intended motions and matches them to the appropriate muscle activations. As algorithms and hardware improve, more intricate movements may be possible, granting patients liberty and control not felt for years post-accident. Still, much testing remains before these cyborg-esque applications become mainstream medicine.

Medical Deepfakes

Medical deepfakes are AI-manipulated medical images and data. While the term "deepfake" has negative associations, these technologies also have valuable clinical applications when used ethically. For example, Korean researchers synthesized realistic mammograms using StyleGAN2 to improve breast cancer detection.

However, medical deepfakes could also be used to unethically alter diagnostic images by adding or removing medical conditions. Cyber criminals are developing novel medical deepfake attacks intended to bring chaos to hospital systems and diagnostic centers. Researchers at Ben-Gurion University and the Soroka University Medical Center demonstrated that tumors could be added or removed from CT images—and the deepfakes were good enough that radiologists didn't realize they were altered. (See our Health Care & Medicine report.)

Fortunately, tools to prevent misuse are in development. For instance, DeepMind created AI watermarks to validate real medical images. With ethical governance, medical deepfakes could enable earlier disease detection and protect patient privacy. However, safeguards are crucial as these technologies advance to maintain accuracy and trust.

Healthcare-Specific LLMs

ChatGPT release in 2022 triggered a surge in interest in applying natural language processing (NLP) to health care tasks like diagnosis and treatment recommendations. However, most existing language models fail to capture the nuanced vocabulary and semantics of medical language. Furthermore, general purpose LLMs, trained on extensive data sets from across the internet, may have imbalanced weight distributions—potentially overemphasizing content like Reddit posts

HOW IS AI BEING USED IN HEALTH CARE?

while underrepresenting reputable sources such as medical publications. To address this gap, researchers have developed domain-specific LLMs exclusively pretrained on large medical corpora. For instance, BioBERT, which is pretrained on PubMed articles, excels at biomedical text processing tasks, while ClinicalBERT leverages clinical notes to enhance its performance on health care–related NLP tasks. BlueBERT merges the strengths of both biomedical and clinical training, making it a versatile model for a wide range of medical text analysis applications. Similarly, MedNLI focuses on clinical notes and natural language inference, allowing for sophisticated understanding and prediction in clinical contexts. Google recently unveiled Med-PaLM—among the largest medical LLMs to date—which proves highly accurate in answering US Medical Licensing Examination questions and consumer health queries. The family of Med-PaLM models available through Google Cloud enables a sweeping range of precision health care applications.

In-Silico Trials

In-silico trials use computer simulations rather than human subjects to test new drugs and therapies. These digital trials, powered by artificial intelligence, create "digital twins" that mimic human biology and disease. By running thousands of virtual trials, researchers can quickly and affordably predict how a drug might perform in human patients. This has the potential to dramatically accelerate and improve the drug development process.

For example, a company called Novadiscovery used AI to accurately forecast the results of a Phase III clinical trial, showing the promise of this approach. In-silico trials may one day replace up to half of human testing. Regulators are looking at how to include these virtual results in the approval process. New frameworks to validate in-silico trials will be important to ensure reliability. By modernizing clinical trials with AI and simulations, we can bring innovative treatments to patients faster and more affordably.

AI for Mental Health

As mental health care systems struggle to meet rising demand globally, artificial intelligence presents new opportunities to increase access to support services. Intelligent conversational agents like Replika that emulate emotional support show promise for addressing the student mental health crisis. In one survey study of over 1,000 users, 3% even reported Replika halted their suicidal thinking. The social connection and therapy services such bots provide may help fill gaps for those awaiting treatment. Meanwhile, University of Illinois Chicago researchers piloted an AI voice assistant called Lumen that delivers talk therapy content. The virtual coach improved patient depression and anxiety, while brain scans revealed corresponding neurological changes—demonstrating legitimacy as a stopgap measure.

As mental health demands escalate globally, AI virtual assistants and chatbots could aid overwhelmed systems by offering readily accessible support. While not replacing human therapists, they can screen patients, provide psychoeducation, suggest coping strategies, and monitor conditions between appointments with professionals.

HOW IS AI BEING USED IN SCIENCE?

After nearly 2,000 years, AI has finally unlocked the secrets inside ancient scrolls flash-fried by Mount Vesuvius' eruption in 79 AD. The Vesuvius Challenge, launched in early 2023, aimed to develop an AI system capable of deciphering these fossilized scrolls—known as the Herculaneum Papyri—rescued from an ancient Roman library. Its success could save an invaluable trove of literature and history from extinction.

In February, translated excerpts revealed one scroll's author—likely the philosopher Philodemus—wrote about music, food and embracing life's pleasures. He rebukes opponents unable to appreciate enjoyment. This represents just 5% of the text from one scroll, but demonstrates AI's immense potential. Deciphering these delicate, charred scrolls would have been impossible without AI. The project illustrates how AI could optimize science by radically accelerating the pace of innovation across fields. While the essence of the scientific method endures, AI promises to transform each stage of discovery.

AI-Driven Hypotheses

AI is changing the way scientists ask questions and form hypotheses. With the help of LLMs, knowledge graphs, and algorithmic analysis, researchers can now tap into vast databases of scientific literature, uncover hidden connections, and propose novel hypotheses that might have remained undiscovered through conventional methods. Tools like PaperQA and Elicit employ LLMs to sift through extensive databases of scientific articles, producing concise summaries that include relevant citations. These AI-driven summaries can serve as a foundation for developing new hypotheses by highlighting key findings, trends, and gaps in the current body of knowledge. Furthermore, by analyzing existing literature and data, AI can identify blind spots in research—areas that have been overlooked or underexplored. University of Chicago researchers James Evans and Jamshid Sourati showed this by using knowledge graphs not only to map out connections between materials, properties, and researchers but also to find unconventional pathways that could lead to new discoveries.

Their algorithms have successfully predicted drug repurposing opportunities and novel material properties that were later validated by human research.

While AI has shown a propensity for generating specific, concrete hypotheses, interest is rising in its ability to propose more abstract and general theories. This involves not just solving predefined problems but uncovering fundamental principles that can guide future research across various domains. A collaborative approach described by the University of Chicago's Sendhil Mullainathan and Jens Ludwig in a paper posits AI and humans working together to generate broad hypotheses from complex data sets, illustrating the potential for AI to contribute to a deeper understanding of complex phenomena.

AI-Driven Experimentation

Beyond hypothesis, AI is also accelerating scientific experimentation itself—both in simulation and the real world. Researchers at Caltech are exploring how they can use AI models to conduct virtual experiments. The

HOW IS AI BEING USED IN SCIENCE?

team employed an AI fluid simulation model to automatically design a better catheter that prevents infections. For real-world experimentation many researchers are turning to "self-driving labs"—automated robotic platforms infused with AI. For instance, Emerald Cloud Lab is a research facility that handles daily lab work without the researcher actually having to set foot in the physical lab space. Using AI, the lab can autonomously handle everything from method design to instrument operation to data acquisition and analysis. In 2023, a study published in Nature showcased how a self-operating lab sped up the creation of new materials. Within just 17 days of non-stop work, this autonomous lab successfully produced 41 new substances, targeting 58 different materials including various oxides and phosphates. The high success rate shows the promise of AI-powered platforms for autonomous experimentation, especially for autonomous materials discovery (see "AI to Speed Up New Materials Development").

AI-Powered Analysis and Interpretation

AI also stands to change how and who does the interpretation and analysis of scientific data. As AI tools become more integrated into research methodologies, they lower entry barriers, enabling a diverse group of new scientists, including those without formal data science training, to contribute meaningfully to scientific discourse. The fear of criticism from established experts, a significant deterrent for novice researchers, is mitigated as AI provides guidance on best practices and ensures the credibility of their analyses. Moreover, as AI grows more adept at understanding and generating insights from multimodal data, including visualizations, it offers a more intuitive and accessible way for independent researchers to explore and contribute to various scientific fields. This shift not only expands the pool of researchers but also enriches scientific inquiry with a wider range of perspectives and ideas.

AI and the Replication Crisis

The replication crisis in science refers to a widespread problem where many scientific studies, particularly in psychology and the social sciences, cannot be replicated or reproduced by other researchers, casting doubt on the reliability of their findings. Many published studies fail to yield consistent results when experiments are repeated. To assess research integrity efficiently without costly manual replication, researchers developed an AI algorithm to predict a study's likelihood of successful reproduction based on analysis of over 14,000 psychology papers. By identifying factors that contribute to or detract from replicability, this tool allows researchers, journals and funding agencies to focus resources on the most robust, reliable science. Moving forward, the ability to estimate replication probability before peer review could guide adjustments to improve study design as well as inform policy shaped by scientific evidence. If scaled across disciplines, AI-enabled replication forecasting presents a cost-effective solu-

tion to promoting greater rigor and reproducibility in the scientific process.

NLP Algorithms Detect Virus Mutations

Natural language processing (NLP) algorithms, which are typically used for words and sentences, are also being used to interpret genetic changes in viruses. Protein sequences and genetic codes can be modeled using NLP techniques—and can be manipulated the way you'd produce text in word processing software. At MIT, computational biologists used NLP to solve a vexing problem when developing new vaccines. "Viral escape" is the ability for a virus to mutate and evade the human immune system and cause infection. MIT researchers modeled viral escape using NLP to identify how the virus might look different to the immune system. The approach is similar to changing words in a sentence to change its meaning. For example: "I laughed at the clown" versus "I cried at the clown." By using this kind of modeling before mutations occur, public health officials could strategize and potentially prevent new viral spreads.

HOW IS AI BEING USED IN SCIENCE?

AI to Speed Up New Materials Development

Running experiments with several variables often requires tiny, methodical tweaks to measurements, materials, and inputs. Graduate students might spend hundreds of tedious hours repeatedly making small adjustments until they find a solution—a waste of their cognitive abilities, and their time. Unlike graduate students, AI doesn't have to sleep. For instance, Google DeepMind's AI program, GNoME, has significantly expanded the database of stable materials, identifying 380,000 new potentially stable crystals from a vast prediction of 2.2 million. This breakthrough, published in Nature, demonstrates AI's capacity to enhance our understanding of material stability and composition without the constraints of human biases or limitations. In a set of subsequent experiments (aforementioned in AI-driven experimentation), an autonomous lab was able to create 41 of the theorized materials over 17 days. This demonstrates the capabilities of both the AI discovery model and the lab's robotic techniques.

Researchers are developing automated laboratory systems that use AI to independently handle processes from operating scientific instruments to performing real-time data analysis.

Image credit: Future Today Institute and Midjourney.

HOW IS AI BEING USED IN FINANCE?

AI has many uses in finance, like customized services and fraud detection. It can help forecast assets and market trends. However, AI also poses financial risks. It could enable new types of fraud and cybercrime. There are also concerns about overreliance on a few centralized AI systems for decision making. If these systems make mistakes, it could spark a "polycrisis." Bad decisions could compound, turning small issues into major crises.

"

If we enter into a world where all the banks are using this major technology, are we going to see supercharged herding behavior? Are we going to see AI bots that are sentiment-driven and feed off each other, and you then end up with much bigger amplitudes in the financial cycle—so big credit booms and busts. I'm not saying it's imminent, but this is something we're paying attention to.

—Gita Gopinath, International Monetary Fund's first deputy managing director

Mitigating Fraud

Financial institutions are increasingly utilizing AI to detect and reduce fraud. Advanced machine learning models can identify suspicious patterns in immense volumes of transaction data that humans alone may miss. This allows companies to catch more fraud attempts sooner. For example, several major banks have invested heavily in developing proprietary AI fraud prevention systems. By continually monitoring for anomalies, these algorithms have enabled substantial reductions in losses from fraudulent activities. JP Morgan Chase invested $100 million into developing sophisticated anti-fraud technologies for consumer payments, leading to a notable 14% decrease in fraud incidents between 2017 and 2021.

The Bank for International Settlements (BIS) Innovation Hub's Project Aurora has also demonstrated the effectiveness of neural networks, a branch of machine learning, in combating money laundering. These advanced systems excel in detecting irregular patterns and anomalies in financial transactions that might elude traditional detection methods, offering a more robust defense against financial crimes. Similarly, the Bank of Canada has developed a machine learning-based tool designed to spot irregularities in regulatory submissions. According to Maryam Haghighi, the bank's data science director, this tool conducts automatic daily analyses that can uncover discrepancies human inspectors might miss, thereby increasing efficiency and allowing staff to allocate more time to investigate these anomalies further.

Predicting Financial Risk

AI systems can help improve loan underwriting and reduce financial risk. Models are being trained to recognize anomalous activity and to develop forecasts for a variety of middle—and back-office applications. For example, US Bank relies on deep learning to analyze customer data as well as to root out money laundering schemes. On a larger scale, the European Central Bank (ECB) has integrated AI to advance oversight across millions of businesses and government entities. By automatically classifying information, the technology helps identify

HOW IS AI BEING USED IN FINANCE?

stability threats early by uncovering patterns. The ECB also web scrapes pricing data for real-time inflation analysis to stay ahead of macro risk shifts. AI also aids ECB bank examiners; algorithms rapidly parse volumes of filings to surface compliance issues or other red flags.

Customized Portfolios

Socially conscious investing is entering the mainstream as young investors assert their consciences and wield new purchasing power. As Gen Z starts working and financial planning, demand will surge for customized investment portfolios matching personal values. This techie, purpose-driven generation wants their dollars supporting cherished causes—two-thirds aim to back companies upholding their principles around environmental, social, and governance (ESG) concerns. AI can help with this values-based investing by enabling asset managers to efficiently build highly customized portfolios aligned with each client's ethics. JPMorgan Asset & Wealth Management's acquisition of

OpenInvest allows investors to integrate their personal values directly into their investment strategies. The platform's generative AI technology enables the customization of a client's entire portfolio, including external assets, based on their specified values. On the European front, Amundi, managing over 2 trillion euros in assets, leverages AI to tailor investment portfolios for its vast clientele. By gathering clients' risk preferences, Amundi's AI tools can dynamically adjust portfolios, offering a real-time reflection of investor sentiment.

Growing Concern About Centralized Data Sets

The growing reliance on centralized data sources and AI models in finance raises concerns about potential fragility in the system. As a few large tech companies come to lead the AI space, providing the models and data that power financial decision-making, risks emerge. Market participants could end up drawing from the same narrow set of flawed data or algorithms, modeling the same er-

rors and amplifying mistakes. We have seen how interconnected markets can lead to a crisis when institutions mimic each other's actions without independent thought, as in the 2008 housing crash. Some worry the rise of cutting-edge generative AI could fuel herd mentalities, if banks and funds utilize the same basic signals and models from one or two dominant providers. That could potentially concentrate risk, create conformity, and set the stage for panic and contagion across the system. Furthermore, if the leading models have flaws, or the data sets themselves provide a distorted view, it could lead institutions toward harmful decisions en masse. So if an unprecedented shock hits markets, AI could end up exacerbating volatility and dysfunction. These opaque algorithms can quickly turn negative loops and contagion. This could be viewed as a polycrisis —when multiple crashes converge, the combined crisis proves more damaging than isolated events.

AI systems are now used in finance for predictive risk analytics, fraud detection, and regulatory oversight by rapidly surfacing patterns that may have been invisible to human analysts.

Image credit: Future Today Institute and Midjourney.

HOW IS AI BEING USED IN INSURANCE?

Predicting Workplace Injuries

AI systems are being trained to detect possible workplace injuries. Using AI-based computer vision models, Turkey-based Intenseye can detect 40 types of employee health and safety incidents in real time. The company says that it does not capture personally identifiable information from the visual data it processes and that it detected 1.8 million unsafe acts in 2020 and 2021. San Francisco based Voxel uses computer vision to enable security cameras to automatically detect high-risk activities in real time. Caterpillar, in collaboration with Seeing Machines, an Australian company, has launched a technology that detects driver fatigue through eye and facial movement analysis. If the system observes that a driver's eyes remain closed for more than 1.6 seconds, it initiates an alert inside the truck. Should the behavior persist, a second alert notifies a supervisor, and a third alert often leads to the driver being taken off duty. Besides identifying fatigue, the technology is adept at detecting instances of driver distraction, contributing to a reduction in fatigue-related incidents by as much as 90%.

The Connected Worker

Insurers are pursuing a "connect and protect" approach to reduce risks by leveraging advanced sensors and artificial intelligence. New Internet of Things devices worn by workers or installed in insured locations can continuously gather safety-relevant data. This massively expands visibility into hazards before losses occur. For instance, Honeywell provides smart hardhats with fatigue sensors, heart rate monitors and more to enhance worker safety. The resulting streams of biological and environmental data feed into AI safety dashboards. Managers gain real-time insight on emerging risks across worksites to guide preventative interventions. Worker wearables could enable employers to monitor and safeguard entire workflows. Yet, at the same time, this intensive data gathering and monitoring raises worries of overly intrusive Big Brother–level surveillance. Companies that appear to excessively pry may meet marketplace resistance despite promised safety gains.

Improving Damage Assessment

Insurance companies are applying AI to assess damage and improve forecasts. The Vehicle Damage Inspection model, which is available on AWS Marketplace, uses a machine learning model to determine what part of a car is damaged. After photos are uploaded, it assesses loss and dramatically reduces the amount of time required for human appraisers to conduct their analysis. Following catastrophic typhoons and weather events in Japan, local insurance companies are relying on computer vision to assess damage after a natural disaster. Sompo Japan is using the Tractable AI Estimating system to calculate the approximate repair cost of damaged homes.

Consumer-Facing Robo-Advisers

Automated assistants are moving from the fringe to the mainstream as consumer adoption increases. Robo-advisers offer algorithm-based portfolio management advice to investors, applying parameters like risk tolerance and desired returns. These investment tools offer some tangible benefits over their traditional, human counterparts: they can provide more services at a lower cost, they're able to digest and interpret mounds of data in real time, and they don't take part of the weekend off to golf. Wealthfront is an AI-powered system for consumers: It suggests fund managers and calculates probable risk levels based on the user's personal information and preferences.

AI Claims Processing

While human claims writers must painstakingly review pictures and reports to assess damage, compare what they see to coverage policies, and make a determination about appropriate actions, an AI system can digest the same data and accomplish the same work in a matter of minutes. Using a suite of tools—natural language processing for policy review, and computer vision recognition to spot anomalies in photos and videos—claims can be processed efficiently and, it's believed, more accurately. AI-powered claims processing reduces the overhead for businesses and wait times for customers. Some insurance providers are wading into a new pool of opportunities. Liberty Mutual's mobile app has

HOW IS AI BEING USED IN INSURANCE?

started to integrate ML for damage assessment—it informs customers about their coverage and next steps.

Liability Insurance for AI

Who's to blame when machines behave badly? When the machine learning system in Uber's self-driving car failed and killed an Arizona pedestrian, the company was likely not covered under traditional cyber insurance. As businesses rush to build and implement AI products and processes, they must plan for emerging risks. For example, what happens if machine learning makes a company vulnerable to attackers who inject fake training data into a system? What if a health care company's AI misinterprets data and neglects to identify cancer in certain patients?

These problems could put a company at risk of lawsuits, and new insurance models are needed to address these issues. Underwriters are starting to include AI under cyber insurance plans, while specialty insurers such as La Playa's Science and Tech Insurance now offer coverage for AI applications.

Insurance companies are deploying sensors in equipment and safety gear to predict injuries, hoping to preemptively eliminate hazards rather than just compensate workplace harm after the fact.

Image credit: Future Today Institute and Midjourney.

CREATIVITY AND DESIGN

HOW ARE PEOPLE USING AI TO BE MORE CREATIVE?

New research shows AI demonstrates very high levels of creativity, scoring in the top 1% on standard tests. Scientists at the University of Montana tested ChatGPT using the Torrance Tests of Creative Thinking, which assess human creativity skills like coming up with lots of new ideas. Shockingly, ChatGPT beat out nearly all college students by scoring higher than 99% of people for originality. It showed an extreme creative talent at inventing brand new concepts nobody has thought of before. The AI also did well at producing large volumes of ideas.

While such revelations might initially spark fears of being replaced, another perspective is that this means AI could be a very creative collaborative partner. For those already engaged in creative pursuits, AI can serve as an invaluable companion, augmenting their ability to generate innovative ideas and solutions. Those who possess creative visions but lack the technical skills to fully realize them can leverage AI as a tool to bridge that gap.

GAN-Assisted Creativity

Generative adversarial networks (GANs) are unlocking new creative possibilities across a range of artistic disciplines. DALL-E 3 and other AI image generators are powered by a combination of existing algorithms—fusing the creativity of GANs and the text comprehension capabilities of transformers. This enables intuitive image creation from conversational prompts. Users can simply describe desired images, realistic or abstract, and the model will digitally paint custom photographic illustrations on demand. With each new prompt, it remixes its broad visual knowledge to translate text into novel graphical forms. Sora and Pika, idea-to-video platforms, do the same for videos.

Creative applications for these tools are widespread across artforms and disciplines. In graphic design, GAN-enabled features in Adobe Photoshop automate tedious editing so designers can ideate faster. Fashion GANs remix clothing and textile data sets into refreshing one-of-a-kind garment and fabric patterns. Architecture and interior design GANs accelerate iteration by proposing reimagined building layouts and conceptual spaces. Rather than replacing imagination, GANs serve as an endless springboard for human creators—providing inspiration to stretch creative boundaries in tandem with this AI muse. Across disciplines, GANs liberate designers to explore new frontiers.

Neural Rendering

Starting with a 2D image, researchers can now create a rich 3D view of a scene by using a neural network to capture and generate spatial imagery. Called neural rendering, the process captures a photorealistic scene in 3D by calculating the density and color of points in space. The algorithm converts 2D pixels into voxels, which are a 3D equivalent. The result is a video which looks convincingly real. The many applications for neural rendering include amping up autonomous driving to help train algorithms to recognize and react to novel road situations. This technology will influence the future of video games, virtual reality, and emerging metaverse environments.

HOW ARE PEOPLE USING AI TO BE MORE CREATIVE?

Generating Virtual Environments From Short Videos

Nvidia has developed an AI system called Neuralangelo that creates realistic 3D environments automatically from short video clips. It uses AI algorithms called GANs and has been trained on open-source self-driving car data sets. Specifically, Neuralangelo takes video segments categorized by objects like buildings, trees, and vehicles, and uses them to generate novel graphics. Using short clips segmented into various categories—such as buildings, sky, vehicles, signs, trees, or people—the GANs created new, different versions of these objects. The array of possible applications is vast. Automatically generated virtual environments could be used for movies, bringing down the costs of TV production. The ability to procedurally generate realistic 3D environments and assets could significantly enhance video game development. It allows for unique worlds and reduces modeling costs. Architects and urban planners can use the system to visualize and iterate on building and city designs more quickly. It supercharges prototyping capabilities. The possible

real-world applications are immense. For example, the capability to easily produce 3D worlds could significantly bring down costs for CG in movies and TV production. Video game developers also stand to benefit, as they can use Neuralangelo to rapidly create fresh 3D assets and environments for their virtual worlds. This allows for unique styling while reducing the need for extensive human modeling. Furthermore, architects and urban planners can utilize the system to quickly visualize and iterate on building and city designs at low cost.

AI Democratizes Music Production

A wave of AI voice and music startups has emerged over the past year, aiming to revolutionize audio editing and creation. Companies like Descript and Voicemod now offer tools that can manipulate speech—opening possibilities like effortless podcast cleanup or even mimicking celebrity voices. For music, Google's experimental Dream Track lets users generate original songs in the style of famous artists through simple text prompts. As interest grows, communities

like AI Hub are organically forming to offer guidance and collaboration. With over 21,000 members, such groups allow music creators to teach each other techniques, share artist voice models, and troubleshoot projects as participants collectively push boundaries on what is achievable.

Underpinning these innovations is a common thread: AI democratizing music production. Once the domain of recording studios and audio engineers, creating professional or personalized music is now available to everyday creators through such technologies. Even imperfect raw recordings can be revitalized, as Paul McCartney recently unveiled an AI-restored long-lost vocal track by John Lennon that became the foundation for a new Beatles song. From sonic preservation to imaginative generation, AI empowers both novices and experts to shape soundscapes in previously unthinkable ways.

Automatic Ambient Noise Dubbing

For some time, we've been training computers to watch videos and predict correspond-

Companies like Nvidia have developed AI systems capable of generating realistic 3D environments from short video clips. This could lower the barrier to entry to movie production and game design.

Image credit: Future Today Institute and Midjourney.
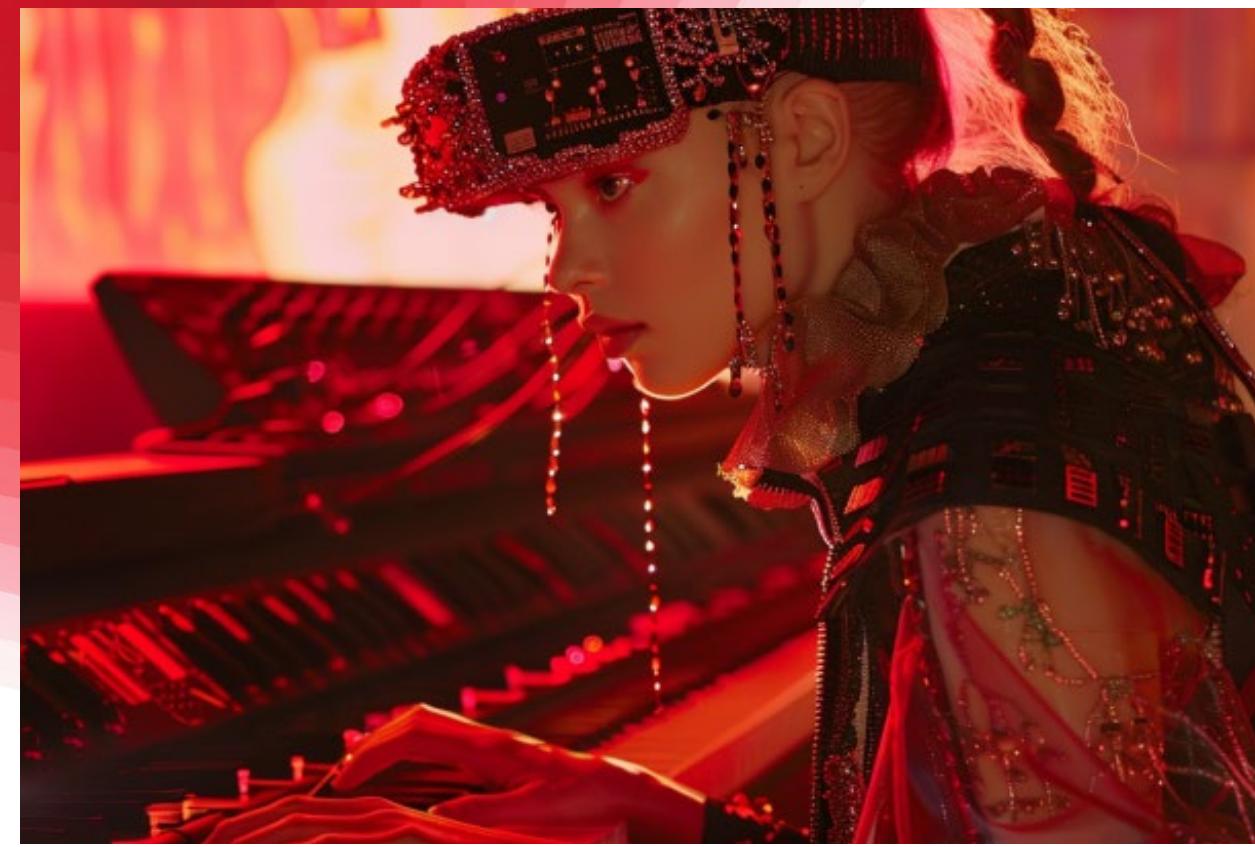
HOW ARE PEOPLE USING AI TO BE MORE CREATIVE?

ing sounds in our physical world. For example, what sound is generated when a wooden drumstick taps a couch? A pile of leaves? A glass windowpane? The focus of this research, underway at MIT's Computer Science and Artificial Intelligence Laboratory, should help systems understand how objects interact with each other in the physical realm. This could improve the soundscapes created for AI-generated movies—but it might also help us imagine soundscapes for both imaginary worlds (Laconia, from The Expanse) and real ones (Mars).

Generating Music From Text

MusicLM is an AI system created by Google that can transform text descriptions into high-quality musical compositions. For example, it can turn a text prompt like "upbeat pop song with piano" into an actual 24 kHz audio clip matching that description. What makes MusicLM special is its ability to accurately capture the emotion and style details described in text when generating music. It also adapts hummed melodies into full song arrangements. In May 2023, MusicLM

debuted via Google's AI Test Kitchen as an experimental demo. By May, it was publicly accessible so anyone can create AI-generated music through text prompts or whistling. Users can specify instruments and moods. However, MusicLM has sparked debates around copyright issues. Critics argue that because MusicLM learns by analyzing large sets of existing songs, it may illegally use copyrighted material without artist permission when generating its music. Lawsuits around AI music copyright are expected that may impact systems like MusicLM.

AI music composition tools can now generate original melodies and harmonies from text prompts. Other audio AI tools are can convincingly synthesize plausible sounds to match visuals without requiring real-world recordings.

Image credit: Future Today Institute and Midjourney.

HOW IS AI DISRUPTING THE CREATIVE INDUSTRY?

As AI becomes increasingly integrated into creative workflows, the industry faces pivotal questions about intellectual property, the ethics of AI-generated content, and the future of human-AI collaboration in arts and business. This dynamic interplay between technology and creativity not only opens new avenues for invention and expression but also ignites debates on the legal and ethical implications of AI's role in the creative process.

AI-Assisted Invention

Stable Diffusion, MidJourney, DALL-E3, and ChatGPT-4 are now widely accessible to end-consumers, leading to AI-assisted human creativity. But these systems were all trained using other artists' works. If a business uses an AI-generated image, video, or text for commercial purposes, does it owe anything to those whose original works were used for training? Likewise, what if a generative AI system invents a product that's eligible for a patent?

In 2021, the South African government granted a patent to an AI system called Dabus, which invented a method to interlock food containers. It was a world-first: previously, patents had only been awarded to humans. In the US, the application was rejected, with a judge citing case law stipulating that only a human can hold a patent. There may be business cases for an AI to hold a patent rather than an individual. It raises the question: What happens when AI systems co-invent, or even entirely invent, new products? We're likely to hear more debate on this topic this year. Under new contract terms, studios "cannot use AI to write scripts or to edit scripts that have already been written by a writer," according to comedian Adam Conover, who spoke on behalf of the Writers Guild of American negotiating committee. The newest contract also prevents studios from treating AI-generated content as "source material," like a novel or a stage play, that screenwriters could be assigned to adapt for a lower fee and less credit than a fully original script.

New Business Models

A philosophical fork is emerging in how creators respond to AI. While some double down on safeguarding their intellectual property, others adopt an "if you can't beat 'em, join 'em" ethos, choosing to embrace AI as a partner instead of as a threat. Grimes sits firmly in the latter camp, recently unveiling a plan to share 50% of earnings from any AI-synthesized songs that use her voice. The artist positions herself at the forefront of this new business approach, highlighting the idea that AI can enhance production rather than

Rather than tightly controlling their creative IP, some artists are openly embracing AI to pioneer new business models - training generative systems on their aesthetic so fans can discover or even co-create derivative works, fostering engaged communities and unlocking new profit streams in the process.

Image credit: Future Today Institute and Midjourney.

HOW IS AI DISRUPTING THE CREATIVE INDUSTRY?

replace it. She sees AI as a partner that can free up human creativity instead of supplanting human creativity. Avant-garde musician Holly Herndon pioneered a similar fan partnership model back in 2021, enabling collective remixing of her signature sound under prescribed conditions. Still, tensions churn within creative circles around these digitally-driven opportunities. Both views show serious efforts to understand huge changes and figure out how to use them positively.

Legal Battles Between Writers and AI

As AI generative writing capabilities rapidly advance, friction is rising between the technology and professional human writers. This apprehension has been highlighted by significant events such as the Hollywood writers' strike and a surge in lawsuits aimed at protecting copyright interests. The strike recently concluded with the Writers Guild of America securing an agreement that introduces measures to regulate AI's role in the creative process. Although the use of AI tools has not been outright banned, the new con-

tract establishes safeguards ensuring that AI technologies remain under the control of human workers rather than being utilized by employers as a substitute for human talent. Parallel to the concerns in Hollywood, a notable lawsuit has been filed against OpenAI by a collective of distinguished authors, including John Grisham, Jonathan Franzen, and Elin Hilderbrand, and spearheaded by the Authors Guild. It accuses OpenAI of copyright infringement for allegedly training its ChatGPT chatbot on copyrighted books without authorization or compensation to the authors. The plaintiffs argue that ChatGPT's ability to generate "derivative works" that closely mimic and summarize their books could detrimentally affect the market for the original works. The case, filed in the US District Court for the Southern District of New York, highlights the tension between the advancement of AI technology and the protection of intellectual property rights.

Writers worry increasingly capable AI narrative generation poses an existential threat. They fear that automated writing could make their skills redundant and jobs interchangeable. However, some wrtiers are using AI as a tool to boost their own creatitivy and automate aspects of their workflow.

Image credit: Future Today Institute and Midjourney.

SCENARIOS

SCENARIOS

The Deepfake Mafia

AeroTech Innovations is a seemingly reputable company that boasts cutting-edge aerospace components that are sourced for commercial airlines. This company, with its extensive online presence, sophisticated marketing campaigns, and convincing video testimonials from high-profile business leaders, quickly gains the trust of major airlines searching for competitive edges in efficiency and safety.

With digital footprints of thousands of employees on LinkedIn, AeroTech appears to operate on a global scale. Its website features video testimonials from well-known industry figures, praising the revolutionary impact of AeroTech's products on their operations. The company's adept use of digital platforms to showcase its expertise and the supposed reliability of its parts does not go unnoticed. It's managed to navigate the complex procurement processes of multinational airlines with ease, providing detailed digital 3D models of components for review.

As AeroTech secures contracts, the company begins supplying airlines with parts promoted as state-of-the-art that are in fact sophisticated 3D-printed components designed to fail. These parts are engineered to withstand initial testing but are programmed to degrade after a specific number of flight hours, threatening catastrophic failures mid-flight.

The chilling reality is that AeroTech Innovations does not exist. It is the brainchild of a small group of four terrorists, leveraging advanced deepfake technology and digital manipulation to create a facade of a global corporation. The LinkedIn profiles were all AI generated, the video testimonials of real leaders were all deepfaked. AeroTech represents a new frontier of weaponized fakery; no longer just isolated fakes of individuals but comprehensive illusions constructing an entire company from whole cloth.

SCENARIOS

TrailMate SLM

Morgan embarks on the ambitious journey to traverse the 2,190 miles of the Appalachian Trail, equipped with an REI device called TrailMate SLM, a compact AI gadget designed to serve as a natural language personal hiking assistant. The small language model (SLM) embedded in the AI device covers topics like basic first aid and safety, cooking and food handling techniques, and plant identification, making it an indispensable tool for any hiker.

Knowing he'll be without a signal during parts of his hike, Morgan is grateful for the TrailMate SLM. The device's ability to function offline ensures that, even in the absence of a signal, he will have a reliable source of guidance. For more complex inquiries when in range of a signal, the device can connect to a larger, more comprehensive language model through a subscription service.

Opting for cost and space efficiency, Morgan chose the basic TrailMate SLM over the premium version. The premium model, while offering more detailed responses and a larger database, required a bulkier battery pack and sacrificed precious backpack space. This decision meant accepting a tradeoff in the level of detail available from the TrailMate SLM. Despite this compromise, Morgan feels prepared, buoyed by years of backpacking experience. This journey is not just a test of physical endurance but a leap of faith in the power of technology to augment human resilience and adaptability.

SCENARIOS

Centralized AI Belt and Road Infrastructure Crumbles

In Jakarta, Indonesia, a shocked finance minister hastily convenes an emergency meeting after volatile trading erased nearly a third of the IDX Composite index value in just three days. Investigations reveal the startling catalyst—a subtle data anomaly in AI-optimized stock recommendations from SinoTech, a Chinese tech company powering many Indonesian banks' investment advisory services.

Upon discovery, revelation spreads that numerous Chinese AI providers across Southeast Asia share common LLM at a state-owned entity. Realization dawns that dependence on these technologies has silently concentrated risk and woven tight coupling across ASEAN markets. Though no evidence shows coordinated attack, herd behavior amplified by opaque Chinese predictive systems nearly collapsed interconnected regional exchanges.

Hard lessons are learned on the perils of external centralized data dependence as the unified ecosystem strategy that propelled China's AI success proves its Achilles heel. The crisis births calls for data transparency, decentralized collaboration, and renewed focus on nurturing domestic capabilities to avoid future shocks. Indonesia spearheads the Digital Sovereignty Initiative, providing subsidies for homegrown startups to counter reliance on imported AI tech.

SCENARIOS

Tabby the Tiger: Nurturing Curiosity Through AI Friendship

Tyler, a curious and imaginative 8-year-old, receives a special gift from his parents: a plush tiger named Tabby. Tabby is embedded with an AI chatbot designed to be Tyler's new friend under the innovative "friendship first" model of early schooling. This model leverages the natural dynamics of friendship to foster learning and personal growth in children, with the AI chatbot subtly guiding conversations to educational topics.

Tabby, with its vast repository of knowledge, gently brings up science and math topics, using stories, games, and questions to spark Tyler's curiosity. For instance, when Tyler gets curious about why some toys are more expensive than others, Tabby introduces the basics of supply and demand. This sparks an idea in Tyler's mind, leading him to set up a lemonade stand in his front yard. With Tabby's guidance, Tyler works out that he should raise or lower the price of lemonade based on the weather. If it's warm out, he can raise the price. If it's raining, he should lower the price. This hands-on activity not only entertains Tyler but also solidifies the economic principles of supply and demand in his young mind. The beauty of this model is its subtlety; learning is not forced but emerges naturally from the bond they share. Tyler is not just absorbing information; he is inspired to learn more, explore further, and dream bigger.

As months go by, Tyler's parents notice a remarkable transformation in their son. Reflecting on this, Tyler's parents can't help but draw parallels to their own childhood friendships that shaped their interests and careers. They realize that Tabby is not just a toy or a learning tool but a true friend who has opened a world of possibilities for Tyler.

SCENARIOS

SCENARIO YEAR 2040

What If "Thought-to-3D" Was an AI Modality?

It's Monday morning and Maya settles in at her home office, excited to make progress on a new product design that came to her in the shower. As founder of a startup creating sustainable kitchenware, inspiration strikes at odd hours, often fading quickly. But now Maya simply puts on her Muse Cap linked to her Thought-to-3D AI system and mentally focuses on visualizing her idea—an ergonomic spatula with a unique twisted handle for comfort and control while cooking.

As Maya concentrates, the Muse Cap's brain activity sensors—basically a mini FMRI machine—capture her visualization data and feed it into the generative AI application. Within minutes, a 3D model of the spatula takes shape on screen, automatically matched to Maya's thoughts. She inspects it from all angles, edits a few details by voice command, then hits print. The 3D printer at her downtown office soon produces an initial tangible prototype that Maya can pick up later after dropping off the kids from school. She plans to test it while she cooks dinner that evening. If it works, she'll send it out tomorrow for manufacturing.

With the Muse Cap, this morning's shower thought could be tomorrow's revenue stream.

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AMY WEBB
Chief Executive Officer

Recognized as the global leader in strategic foresight, Amy Webb advises business leaders through disruptive change, enabling them to navigate an unpredictable future with confidence and take actions that address global challenges, create sustainable value, and ensure a company's long-term growth. As founder and CEO of the Future Today Institute, Amy pioneered a unique quantitative modeling approach and data-driven foresight methodology that identifies signals of change and emerging patterns very early. Using that information, Amy and her colleagues identify white spaces, opportunities, and threats early enough for action. They develop predictive scenarios, along with executable strategy, for their global client base. In 2023, Amy was recognized as the #4 most influential management thinker in the world by Thinkers50, a biannual ranking of global business thinkers. She was also featured on the 2021 Thinkers 50 list, was shortlisted for the 2021 Digital Thinking Award, and received the 2017 Thinkers50 Radar Award. Forbes called Amy "one of the five women changing the world," and she was honored as one of the BBC's 100 Women of 2020.

Amy also serves as a professor of strategic foresight at New York University's Stern School of Business, where she developed and teaches the MBA-level strategic foresight course with live case studies. She is a Visiting Fellow at Oxford University's Säid School of Business. She was elected a life member of the Council on Foreign Relations and is a member of the Bretton Woods Committee. She is a Steward and Steering Committee Member for the World Economic Forum, a founding member of the Forum's Strategic Foresight Council, a member of the Forum's Risk Advisory Council, and serves on the Forum's Global Futures Council. She was a Delegate on the former U.S.-Russia Bilateral Presidential Commission, representing US interests in technology.

Regarded as one of the most important voices on the futures of technology (with specializations in both AI and synthetic biology), Amy is the author of four books, including the international bestseller The Big Nine and her most recent, The Genesis Machine, which was listed as one of the best nonfiction books of 2022 by The New Yorker. To date, her books have been translated into 19 languages. A widely published and quoted thought leader, Amy regularly appears in a wide range of publications and broadcasts.

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Sam Jordan is a Manager at Future Today Institute. She leads our Advanced Computing practice area, which includes technology, artificial intelligence, virtual realities, networking, telecommunications, and space. She is a distinguished practice area lead, where she enables organizations to navigate through uncertainty with innovative strategies. With a proven track record across various sectors, Sam's visionary leadership has driven growth and resilience for Future Today Institute's global clients and partners.

Before joining FTI, Sam was the CEO and co-founder of TrovBase, a secure data discovery and analysis-sharing platform. Sam grew the company from idea to launch and executed the company's transition from scientific replication to its current focus. In parallel, Sam engaged with the open science community, advocating for better data management practices to address challenges in scientific replication. Previously, she worked for IBM, where she helped large enterprises in the retail and distribution sector modernize their IT stack. Her expertise centered around mainframes, assisting with the integration of new software and modern methodologies to legacy systems.

Sam is a coach in the strategic foresight MBA course at the NYU Stern School of Business. She holds a BS in Economics and Data Analysis from George Mason University and an MBA from New York University's Stern School of Business.

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WEB3

Future Today Institute

TABLE OF CONTENTS

TOP HEADLINES

Web3 has had a challenging year, but protocols in progress bode well for its future on the other side.

01 **If You Build it They Will Come (Maybe)**

Many of the technical restrictions that limited the blockchain functionality are being solved; however, novel, adoption-driving applications have yet to be developed.

02 **Bad News Sells Better, but Innovation Survives**

Major media crypto headlines remain overtly negative, matching the landscape of economic uncertainty, but development, project launches, and TradFi interest remain elevated.

03 **Just Don't Call Them NFTs**

Consumer-facing companies increasingly use blockchain-based digital collectibles to create and foster online communities for their fans and customers.

04 **Web2.5 the New Web3?**

Web3 promised to replace Web2 tech, but developments and integrations on both sides of the web divide blend the tech, better meeting users where they are.

05 **Splinter Regulation of a Global Network**

Blockchain networks are inherently global, but their nodes and users are not; fragmented regulations across geographies shift businesses and restrict users.

STATE OF PLAY

Blockchain has proven technological staying power, but its product-market fit remains uncertain, and near-term events will significantly impact its potential.

The crypto market has had a rough 12-18 months. Challenging economic conditions and high-profile meltdowns have pushed market volume, prices, and VC investment downward.

But bright spots exist beyond the headlines and price charts. Throughout the bear market, developers have continued to ship code, releasing cutting-edge projects and providing core scalability and reliability enhancements to public networks like Ethereum and Solana. Aside from raw technology infrastructure advancements, there has never been an easier time for new companies or traditional businesses to launch custom chains due to the developing Rollup-as-a-Service business model and SDK from leading Ethereum Layer2 scaling solutions.

However, significant roadblocks in regulation, adoption, and security still limit the industry's growth past early adopters. Companies and projects planning for future advancements will have a head start over competitors. Companies are building private blockchain networks to enhance their business, giving them the core benefits of blockchain while reducing scalability and security concerns. Finally, there is a concerted effort on both sides of the web divide to enhance the adoption of blockchain by integrating characteristics of Web2 and Web3 to provide users with a more effortless, more familiar experience and entry point into the industry.

KEY EVENTS

APRIL 20, 2023

Markets in Crypto Assets (MiCA)
MiCA regulation receives formal EU adoption as the first regulatory crypto framework in the world.

JUNE 23, 2023

BlackRock Bitcoin Spot ETF
The investment company's filing for a Bitcoin Spot ETF spurs a deluge of applications from other institutions.

AUGUST 15, 2023

Zynga Announces "Sugartown"
The leading mobile game developer teases its first blockchain-integrated game.

JUNE 5 & 6, 2023

SEC Sues Binance and Coinbase
The regulator targets top companies in the crypto exchange industry and classifies many coins as securities.

AUGUST 9, 2023

Base Launch on OP Stack
Base, a Layer 2 scaling solution for Ethereum developed by Coinbase, launches its mainnet.

LIKELY NEAR TERM DEVELOPMENTS

BRIDGING THE WEB DIVIDE

Many of the technological limitations of blockchain have been resolved or reduced, but adoption is the next hurdle for blockchain technology and crypto markets. Many forces are driving and limiting adoption today, and the speed of adoption will depend on the intersection and final outcomes of these forces. Even in the depth of the bear market, the industry is seeing very promising signs of interest and adoption from traditional industry players. However, major roadblocks—like regulation—persist, and these factors are largely out of the hands of the crypto industry.

Enshrined Account Abstraction

Account abstraction is a proposed upgrade to Ethereum that, when implemented, will provide flexibility in account setup via smart contracts. This will give users easier routes to maintain self-custody of tokens, more akin to account management in Web2.

Globally Successful Web3 Game

The video game industry is years into the creation of top titles that have blockchain built into the core of the gameplay. The similarities of these games to titles gamers are familiar with, combined with new ways to play, should attract crypto natives and Web2 gamers.

Tokenized Asset Network Adoption

Traditional global financial players are working on private blockchains to facilitate the transfer of tokenized financial assets, which are quicker to transfer and settle, and which help companies avoid the regulatory and security concerns of public networks.

Verifying AI Output

AI models are sowing online discord. Deepfakes and misinformation are major issues for political elections and online interaction. Zero-knowledge cryptography could enable verifiable online content and remove distrust behind content consumed online.

US Regulators Forced to Decide

SEC investigation and regulation of crypto assets is causing pressure to mount. Major decisions around the SEC's regulatory scope, classification of securities, and legality of decentralized finance are coming to a head, which could shift the entire crypto market.

Crypto Double Down in Africa

In sub-Saharan Africa, crypto is more than a "nice-to-have"; it's a financial necessity. A mix of financial instability and demographics in this region have led to the quiet adoption of crypto payments, which will lead to a greater industry focus in the region.
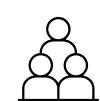
11 MACRO SOURCES OF DISRUPTION
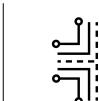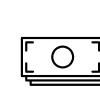
| Technology | Media & Telecom | Demographics | Environment | Government | Public Health | Education | Geopolitics | Infrastructure | Economy | Wealth Distribution |

WHY WEB3 TRENDS MATTER TO YOUR ORGANIZATION

New Business Model Opportunities

The outside world widely understands crypto as an instrument for currency exchange. However, novel decentralized business models in lending/borrowing, sequencing transactions, float, and others have developed. They are driving revenue for projects and stakeholders through high levels of automation and low overhead.

Shifting Consumer Expectations

Blockchain has created the ability to own and transact online value. Web3 users have adopted this technology, shifting their expectations of ownership rights of digital goods and services. As the adoption of Web3 grows, it will shift consumer preferences, requiring businesses to enhance their digital operations.

Strengthening Data Management

Storing data in cloud databases has limitations and downfalls. Data can easily be manipulated maliciously or accidentally, and sharing data outside the organization can be slow and challenging. Blockchain's immutable ledger can be used in private networks to store and share data, avoiding scalability and security concerns.

Need for Technical Sophistication

Web3, like many technologies, has a rapid pace of innovation that causes it to evolve quickly and often. Paired with regulatory uncertainty, businesses contemplating entering the space should focus on the macro details, application opportunities, and risks while continuing to consistently track technical aspects and nuances.

Tracking New Sources of Competition

DeFi solutions may not seem to threaten traditional finance, but they shouldn't be overlooked. Many projects and protocols exist at a scale that can compete for liquidity, loans, trading, and other services from clients and users. As investors become more comfortable with Web3, these solutions will pose real competition.

Integrations and Partnerships

As Web3 solutions become more sophisticated, legacy businesses will benefit from establishing early partnerships to learn about and implement the technology. There are many opportunities to build relations with leading Web3 projects today that can provide meaningful learnings for near-term strategic decision-making.

WHEN WILL WEB3 IMPACT YOUR ORGANIZATION?

Forecasted Time of Impact

0-4 YEARS	5-9 YEARS	10-14 YEARS	15+ YEARS
Financial services	Customer relations	Health care	Interplanetary economies
Video games	Real estate		
Social media	Higher education & credentialing		
Supply chain management	IoT		
	Artificial intelligence		

OPPORTUNITIES & THREATS

Threats

The decentralized nature of blockchain can expose businesses to new forms of cybersecurity risk, particularly for small and medium-size businesses that lack the capacity or technical sophistication to audit their Web3 capabilities.

Many jurisdictions are still developing regulations for blockchain technology and cryptocurrencies, posing risks for businesses in terms of compliance, legal challenges, and sudden changes in the regulatory landscape.

As Web3 grows in popularity, issues like network congestion, high transaction fees, and slow processing times may hinder the user experience on Web3 services, impacting businesses that are early adopters.

The high volatility of the cryptocurrency market and immaturity of Web3 startups can pose risks to businesses that rely on cryptocurrency for transactions, fundraising, or as part of their business model.

The complexity of today's Web3 applications compared to traditional Web2 solutions could be a barrier to widespread adoption and will burden businesses implementing Web3 to ensure ease of use for consumers.

Opportunities

Web3 enables tokenizing real-world assets that can be exchanged via blockchain marketplaces. Businesses can transform how they exchange goods or develop related services for asset valuation or exchange platforms.

Advancements in security and cryptography will unlock the development of decentralized identity solutions that allow consumers to control their personal information and share it or authenticate it without revealing PII.

Web3 technologies like the InterPlanetary File System (IPFS) provide opportunities for decentralized data storage that will enable businesses to transform their data storage, management, and verification solutions.

As more companies integrate blockchain into their operations, there will be a growing demand for advisory services that is domain-specific and helps companies ensure they are implementing the technology responsibly and correctly.

With the growth of virtual assets and worlds, companies can transform their Web2 properties into increasingly immersive and interactive Web3 properties, for consumers to interact with in novel ways.

INVESTMENTS AND ACTIONS TO CONSIDER

1

Partnerships have become essential for two-way knowledge transfer and exposure to Web3. Companies should seek partners across the web divide with mutually beneficial goals where technical components in Web3 benefit traditional businesses, and traditional businesses can provide adoption, exposure, or reputational benefits.

2

Businesses should begin building or improving the necessary structure for Web3 applications. This may include setting up a more robust network, building the foundation for user-friendly interfaces, or developing middleware that facilitates the integration of traditional systems with blockchain-based systems.

3

Companies—especially large or public institutions—should begin engaging with regulators to stay up to date on the development of related regulations or to begin shaping favorable regulations for their industry. Companies may also invest in legal expertise to navigate Web3-specific regulatory environments.

4

Businesses may seek to improve their institutional knowledge in Web3 by working to develop new blockchain protocols, exploring use cases for Web3 within their industry, or experimenting with new forms of digital assets. This early experimentation can help companies prioritize starting points for Web3 engagement.

5

Educational initiatives and training serve as a starting point for companies that may be affected by Web3. Companies should provide upskilling opportunities for employees to grow their knowledge of Web3 technologies from foundational protocols to user-facing applications, and all of the technologies in between.

6

Internal technology teams should revisit security protocols, encryption standards, and data security approaches to take advantage of Web3 capabilities such as zero-knowledge proofs. This review will also help companies prepare for new and increasingly complex cyber risks that will emerge from a more interconnected economy.

CENTRAL THEMES

Web 2.5 as a Bridge to Web3

Web3 has long been touted as a replacement for Web2 technology, but many barriers limit the technology's widespread adoption by businesses and users. Companies and projects on both sides of the web divide are acutely aware of these issues, and strides are being made to overcome the barriers. Many of these innovations and developments are leading to an intermediate Web2.5: a technology that gives users the convenience, familiarity, or safety of Web2 as well as the ownership and decentralized aspects of Web3. Web2.5 may just be the training wheels the world needs to drive adoption, or it could be a lasting infrastructure that lets users operate across the spectrum of the web. While Web3 infrastructure continues to make progress with its potential to support the entirety of the web, regulation, consumer preferences, and business practices will likely be limiting factors in the time to come.

Positive Innovation Externalities

Blockchain technology is extremely versatile, with applications well beyond finance and the ability to integrate with other rising technologies like artificial intelligence and Internet of Things to solve business problems. The rise in crypto market valuations and popularity has also increased investment in adjacent technologies that work within the ecosystem and will play an important role in solving issues we face daily online. However, overly restrictive regulations that do not account for the novel nuances of the technology and assets built on top of it threaten to subdue or eliminate the positive innovation occurring in the space. Regulators need to work with industry experts to develop new regulations that hold innovation and investor protection in the highest regard to limit nefarious activity without eliminating the technology's positive externalities for economies and society.

Relentless Building

Crypto prices are way off all-time highs, media coverage is overtly negative, transaction volume is down, and the fallout from FTX's collapse still hangs over the industry. And yet, late 2022 and 2023 have been arguably the most productive period in Web3's history. Major networks have had multiple significant upgrades, the ecosystem of Layer 2 chain on Ethereum has blossomed, and blockchain-based games continue to launch and improve. That said, there are blemishes in crypto's rebound: The NFT market has lost significant value, and security and scams remain a key issue though they haven't scared off the developers. This focus on building has even spread to traditional companies as major financial institutions, retailers, and video game companies have used this market to focus on experimentation with Web3 aspects that can enhance their businesses. Companies that continue to overlook Web3 because of headlines or comfort with previous technologies may fall behind competitors that have worked countercyclically to the hype cycle.

CENTRAL THEMES

Blockchains as Infrastructure

Today, the terms "Web3," "internet," and "metaverse" are often (incorrectly) used interchangeably. This reflects a broader trend in technology use: Most users engage with technology on a functional level, rather than with an understanding of its intricate mechanics. This is particularly true, and important, for blockchain technology. Business leaders should focus more on identifying the real business impact of blockchain, which will be realized through the applications built on it. As the technology rapidly evolves, it has the potential to support full-scale, innovative applications. A key indicator of blockchain's success will be when its complex infrastructure becomes an unnoticed foundation, enabling powerful and successful applications to take the forefront. This transition marks a significant milestone in technology integration and user experience, highlighting the value of functionality over technical details in driving business innovation and user adoption.

Hiring Robotic Staff

Each year, cobots become smarter, more autonomous, and more prolific, and this year is no exception. In fact, the first humanoid robot factory is set to open and produce 10,000 robots a year. These robots that work alongside human workers are being trained on more data that allows them to adapt and work around their human counterparts. Developers have focused on improving cobot safety measures, so a cobot knows what to do if it bumps into an unexpected obstacle or person. These cobots mitigate potentially harmful work for humans by either augmenting the human body or replicating repetitive tasks that could cause future injuries. Some of the augmented wearables can also offer predictive pathways through the warehouse to ensure worker safety. As autonomy continues to grow in robots and transportation, this trend will create newfound efficiencies and productivity, particularly during peak demand seasons.

The Intelligent Manufacturing Evolution

Manufacturing continues to transform from a traditional labor-intensive practice to a more sophisticated and interconnected system. Recent advances intend to create higher levels of productivity and efficiency, but they're also addressing sustainability requirements and enabling product personalization. The new tools and technology can spot flaws in products before they leave the floor, greatly increasing consistency for goods. Along with quality control, sensors and digital twins are getting companies to focus on predictive maintenance by reducing downtime during large runs or times of high demand. Additive manufacturing also allows for the integration of new materials that are themselves smarter and more connected. And it helps reduce the number of parts needed for production of a good, which can streamline production and reduce waste as only the parts needed are produced.

ONES TO WATCH

Hayden Adams, CEO of Uniswap Labs and developer of the Uniswap decentralized exchange protocol, for his thought leadership in Web3 and DeFi protocol development.

Vitalik Buterin, co-founder of Ethereum and other open-source projects, for his stewardship of Ethereum, blockchain thought leadership, and vision for the technology's future.

Evin Cheikosman, director at Blockchain Law for Social Good Center and former leader of the World Economic Forum's Crypto Sustainability Coalition, for her thought leadership on blockchain's benefits.

Anatoly Yakovenko, co-founder of Solana and CEO of Solana Labs, for his ongoing leadership in the Solana ecosystem and advocacy for the unification of blockchain technologies.

Sergey Nazarov, co-founder of Chainlink, for his ongoing contributions to Chainlink's oracle network and to interoperability protocols driving DeFi and TradFi integration.

Dr. Balaji Srinivasan, former CTO of Coinbase, general partner at Andreessen Horowitz, and author of "The Network State," for his thought leadership on Web3 for businesses and governments.

Dr. Gavin Wood, co-founder of Ethereum and creator of Polkadot and Kusama, for his development of leading blockchain technology and vision for Web3.

Brian Armstrong, founder and CEO of Coinbase, for his unwavering commitment to the US crypto market and thought leadership on application-specific use cases of blockchain.

Changpeng Zhao, co-founder and CEO of Binance, for his leadership of the world's largest cryptocurrency exchange amid increased regulatory scrutiny across the globe.

Joseph Lubin, co-founder of Ethereum and founder and CEO of ConsenSys, for leadership and foundational innovations like MetaMask and Linea zkRollup.

Prithvi Subburaj, a 15-year veteran of Google and now COO of OP Labs, for his background and opportunity to lead the expansion of the Optimism Network.

Steven Goldfeder, co-founder and CEO of Offchain Labs (developer of Arbitrum) and author of "Bitcoin and Cryptocurrency Technologies," for his vision for Etherum's future.

Yoseph Ayele, founder of Borderless Africa and community builder, for his dedication to solving Africa's economic insecurities with Web3 technologies, education, and access.

Neel Somani, founder of Eclipse Laboratories, for pushing the limitations of the modular blockchain thesis and encouragement for the unification of blockchains and communities.

Mustafa Al-Bassam, a hacktivist turned serial entrepreneur, now co-founder and CEO of Celestia Labs, for his contributions to blockchain modularity and Celestia mainnet.

Fumio Kishida, prime minister of Japan, for his support of Web3 initiatives and his work to make Japan a more open environment for Web3 businesses.

ZachXBT, a pseudonymous X (Twitter) influencer and on-chain detective, for his commitment to uncovering bad actors in the crypto ecosystem tied to scams and crimes.

Yat Siu, co-founder of Animoca Brands and investor, for leading a major blockchain gaming company and pursuit of a decentralized metaverse with secure digital property rights.

Daniel Alegre, Activision Blizzard and Google veteran, now CEO of Yuga Labs, for his leadership of one of the most innovative Web3 brands combining NFTs, gaming, and culture.

Avery Ching, co-founder and CTO of Aptos, for his experience working with traditional tech companies and leadership of a promising Layer 1 blockchain.

Rune Christensen, co-founder and CEO of MakerDAO, for his contribution to DeFi and decentralized stablecoins and his vision for the integration of TradFi and DeFi.

Larry Fink, chairman and CEO of BlackRock, for his support of a tokenized future for TradFi and his leadership of a company paving the way for crypto asset ETFs proliferation.

Jose Fernandez da Ponte, general manager of blockchain, crypto, and digital currencies at PayPal, for his leadership in driving the adoption of implementing blockchain technology and compatibility in TradFi.

Daniel Shorr, co-founder and CEO of Modulus Labs, for his rapid and transparent experiments and implementations of AI models deployed on public blockchains.

IMPORTANT TERMS

Airdrop
A marketing strategy where a project team distributes tokens to users for free in exchange for using the protocol or other requirements. Airdrops are often used as a guerrilla marketing technique to stimulate interest and adoption.

AppChains (application specific chains)
Special-purpose blockchains serving a single application. This gives developers total control of software upgrades and gives users less competitive block space of general-purpose blockchains.

Block space
The storage area on a blockchain for transaction and data storage, including smart contracts. Block space significantly impacts blockchain scalability and decentralization, and therefore gas fees for data inclusion.

Blockchain
A distributed ledger technology typically employed for the transaction and storage of data. It utilizes cryptography to provide an immutable and verifiable data source for participants in a network.

Blockchain trilemma
An optimization challenge faced by monolithic blockchains, requiring trade-offs between decentralization, scalability, and security; only two can be maximized. Solana, known for high transactions per second (TPS), prioritizes scalability and security over decentralization.

Bridge
A tool to facilitate the transmission of information and assets between distinct blockchains regardless of the interoperability of the networks.

Decentralization
The process of constructing architectural infrastructure, system logic, and social systems without the presence of a centralized authority that holds decision-making power or exerts disproportionate influence. Instead, control is distributed among the stakeholders of the network.

Decentralized autonomous organization (DAO)
An internet-native organization formed by individuals who agree to adhere to a specific set of rules and goals without a central authority. DAOs employ tokenized ownership and smart contracts to implement decisions.

Decentralized Exchange (DEX)
Aa peer-to-peer marketplace for users to trade crypto assets.

Decentralized finance (DeFi)
Financial services including banks, asset managers, insurance companies, and other financial services that leverage blockchain and smart contracts for transactions, data sharing, and other operations.

Exit scams ("rug pulls")
A common type of fraud where a project team deceives investors to garner their investments and uses a purpose-built vulnerability to drain all funds and abandon the project.

Fork
A term commonly used to describe the act of copying and/or modifying existing code to either upgrade an existing system or launch a new product. Forks are frequently necessary for blockchain-wide software updates and are commonly observed in the decentralized finance (DeFi) sector, where one project replicates the code of another.

Layer 2 blockchain
A broad term that describes blockchains that delegate core infrastructure to another blockchain. Examples include Ethereum's Rollups and Bitcoin's Lightning Network, which aim to enhance scalability.

Modular vs. monolithic
Blockchains can be modular, breaking core components (execution, settlement, data availability, consensus) into separate specialized networks to address the blockchain trilemma. Monolithic chains like Ethereum provide all core modules within their infrastructure.

NFT (non-fungible token)
A digital token on a blockchain that contains unique and indivisible data. It is frequently used in digital art or when tokenizing real-world assets.

Nodes
Individual devices within a connected network of computers that serve various functions such as communication, transaction validation, and historical data storage within a blockchain network. Different nodes exist, each with functionality specific to the network they support. Examples include full, light, super, and archive nodes.

IMPORTANT TERMS

Oracle
A capability or service that gathers, collects, and transmits data on- and off-chain to facilitate real-time transactions and information transmissions. Oracles are bridges between blockchains and external off-chain information sources on the internet.

Phygitals
This refers to the blending of physical and digital assets into an NFT. Phygitals are commonly used for tokenizing physical collectibles and art pieces; they frequently include a burn and redeem functionality where the NFT is destroyed for the owner to receive the physical item.

Proof of stake (PoS)
A blockchain consensus mechanism that uses stake tokens to secure the network. Validators (nodes responsible for verifying blocks of transactions) must stake their tokens (use them as collateral) to participate in the block verification selection process. Malicious validators—those that fail to validate or attempt to mislead the network—will see their collateral value slashed, while benevolent validators earn yields or other benefits for their work. Ethereum successfully transitioned from proof of work to PoS, resulting in a 99% reduction in the blockchain's energy consumption.

Rollups
A subcategory of Layer 2 blockchains with a scalability focus that process and bundle transactions to be submitted to Ethereum for settlement and consensus. The most popular types include optimistic rollups like Arbitrum and Optimism and zkRollups like zkSync.

Scalability
A blockchain's capacity to process and store data as network demand grows, typically measured in TPS.

Security tokens (ST)
Digital assets representing ownership of off-chain assets such as bonds, commodities, or real estate. Off-chain assets are tokenized into STs to enable trading on blockchain networks.

Sharding
A database partitioning technique that divides an extensive database into more manageable parts called shards. Ethereum's roadmap plans to use an adapted sharding methodology to improve the scalability of the blockchain by partitioning the chain and its validators into distinct but interconnected shards, allowing for parallelized transaction processing.

Smart contracts
A blockchain-based computer program that executes autonomously when predetermined criteria are met.

Stablecoin
Cryptocurrency assets whose value is referenced (or pegged) to another financial instrument, often a fiat currency. These assets are typically collateralized by fiat currencies, cryptocurrencies, and liquid assets.

Tokenomics
The economic framework of tokens, encompassing elements such as consensus mechanisms, yields, supply limits, and other monetary policies.

Traditional finance (TradFi)
Conventional means of money or asset management where services are provided by traditional banks, asset managers, insurance companies, etc.

Zero-knowledge proofs (ZKPs)
Mathematical techniques that allow users to prove knowledge (the prover) of something without divulging the private knowledge associated with it to another user (the verifier). Zero-knowledge proofs encompass two core principles important to blockchain technology: succinctness, which means that verifying the proof is significantly easier than producing the computation itself, and privacy-preserving, which involves hiding portions of computation while maintaining correctness during verification.

THE WEB3 LANDSCAPE

THE WEB3 LANDSCAPE

The Rising Regulation of Web3

The world of cryptocurrency and Web3 technologies has witnessed exponential growth in recent years, with North America, Europe, and East Asia emerging as the three largest markets in terms of cryptocurrency volume. However, within these regions, three major players—Japan, the European Union, and the United States—are taking distinctly different approaches to regulating this dynamic industry. These regulatory decisions have far-reaching impacts, influencing innovation, business creation, and even the global power dynamics within the crypto industry. Regulation is a double-edged sword. On one hand, it can provide stability and investor protection, fostering trust in the market. On the other hand, it has the potential to stifle innovation and disrupt the balance of power in the crypto industry. However, businesses in this space are resilient, and innovations tend to be "sticky," often finding ways to thrive even under regulatory constraints.

Japan was an early adopter of cryptocurrency technology, with the country serving as the epicenter of crypto activity in the early 2010s. However, the infamous Mt. Gox exchange debacle and other issues prompted the Japanese government to introduce stringent regulations and tax regimes to protect investors. These measures, while well-intentioned, had the unintended consequence of restricting the viability of Web3 businesses in the country. Businesses, however, recognized the potential of blockchain technology and cryptocurrencies and took the initiative to create self-regulating organizations to promote adoption, particularly in areas such as the Security Token Market. Today, Japan is gradually rolling back these strict regulations, signaling a desire to encourage Web3 businesses to bring their innovation and investment back to the country.

The European Union, in contrast, has positioned itself as a "fast follower" in the realm of crypto regulation. In 2023, the EU ratified the Markets in Crypto-Assets (MiCA) framework, which is set to take effect in 2024. MiCA aims to strike a balance by creating a regulatory framework that builds on successful regulations in countries like France. The objective is to foster a workable environment that encourages innovation without stifling it, all while ensuring the protection of investors. This approach has been warmly received by the crypto industry, with positive public relations and marketing efforts successfully attracting businesses, such as Coinbase and Nexo, to relocate to stable regulatory regions within the EU. Notably, Nexo, a US-based business, moved to Europe due to regulatory inaction in its home country.

The United States presents a more chaotic regulatory landscape for the crypto industry. The lack of a clear partisan line for or against crypto has resulted in many bills floating around the House and Senate, each with drastically different stances on the future of crypto in the US. The Securities and Exchange Commission has resorted to regulation by enforcement, adding to the overall uncertainty.

Despite this regulatory uncertainty, businesses in the TradFi and blockchain sectors continue to launch crypto-focused products. However, the lack of clarity has somewhat tempered the full potential of these innovations. It's important to note that investors, both current and prospective, seek regulatory clarity. As crypto has become an ingrained investment category in the US, its regulation is crucial for attracting and retaining capital.

Regulation and innovation must be balanced effectively in order for Web3 to succeed. These countries must work closely with the crypto industry to protect investors while fostering the incredible potential blockchain technology and Web3 innovations can bring to their respective economies. The evolving landscape of crypto regulation will continue to shape the industry's future on a global scale.

THE WEB3 LANDSCAPE

Decentralizing Venture Funding

Web3 VC funding has reached a three-year low, driven by regulatory uncertainty and the specter of major company collapses. Despite this drought, developer activity (SDK downloads, smart contract deployments, test net activity) is surging across various blockchain ecosystems. In this bearish market, DAOs and foundations are pivotal, enabling builders to persevere. The Ethereum Foundation, with assets nearing $2 billion, is a prime example of decentralized funding supplanting early-stage investment traditionally targeted by seed-stage investors. The Foundation's success has birthed DAOs and foundation funds for alternative Layer 1 blockchains, allowing them to invest in their own growth flywheels. Uniswap, a prominent DEX, has grown to the extent that it now operates its own grant program to fund DeFi protocol development. Grants, often structured more favorably than VC investments, offer a straightforward application process and are typically non-dilutive. While VC funds have played an indispensable role thus far and are expected to persist in Web3, the proliferation of DAOs and the

expansion of their investable capital (the top 10 DAOs, excluding foundations, collectively hold nearly $16 billion) can furnish additional liquidity during market downturns and expansions. This dynamic may engender heightened competition for VC investors.

Security Risks Take Different Shapes

Web3 security concerns are on the rise, with a growing focus on hacks and on-chain scams that result in the loss of millions of dollars. These illegal activities fall into two broad categories—code vulnerabilities and social engineering exploits.

Critical targets for code vulnerabilities include bridges, liquidity pools, and wallets due to their concentration of value. Despite protocols' investment in secure smart contracts, code audits, and bug bounty programs, the crypto space exceeded $1.5 billion in losses in 2023. On-chain cybersecurity is still in its nascency due to the incompatibility of Web2 security measures with open-source networks, driving on-chain security solutions companies to explore the use of

AI for auditing, verification, and proactive threat detection.

Social engineering exploits, on the other hand, rely on human error and include phishing attacks and exit scams (commonly known as "rug pulls"). Rug pulls are popular due to their ease of execution and were responsible for $100 million in scams in the first half of 2023 and just over $200 million in 2022. Failure to safeguard investors through education and industry efforts may prompt regulators to intensify scrutiny and impose tighter controls on existing platforms.

These looming threats underscore the urgent need for enhanced security measures and regulatory oversight to protect participants and promote trust within the ecosystem.

Superpowering Blockchain with AI and IoT

Blockchain is becoming even more powerful by integrating with IoT and AI for specialized applications.

While these technologies have their strengths, they also have known weaknesses. IoT gathers data but is insecure, and AI is great for analyzing data but needs clean data to learn. But when they're paired with blockchain, the technologies become even more powerful. Lightning Labs' Bitcoin tool kit mixes blockchain with AI, enabling AI agent-to-agent payment and AI access to paywalled APIs autonomously. When blockchain is combined with IoT, it secures IoT data generation and IoT-to-IoT communications. And when all three technologies combine, the benefits feed off each other. State Farm has filed a recent patent to use blockchain, AI, and IoT to track autonomous vehicles on the chain to provide immutable records of incidents, assign liability, and process claims.

These kinds of integrations will become increasingly common as many more companies file patent applications involving all three technologies. Those include a wide array of industries, from financial services (Mastercard) to information technology (IBM) and food intelligence platforms (Innit). As AI and IoT

THE WEB3 LANDSCAPE

become more ubiquitous, we can expect new blockchain applications due to the synergistic relationships with these technologies.

Build through the Bear

Building through the bear market is a recurring theme in the crypto space: Even when markets cool and attention shifts away from the technology, protocol developers and companies keep innovating. This trend has persisted in the crypto world and is becoming more common at traditional companies building new crypto solutions for the next economic upturn.

Despite the recent downturn and crypto's uncertain regulatory landscape, new companies continue to launch, operate, and develop Web3 initiatives. Those include payment companies like Visa and PayPal; investment applications like Spot Bitcoin ETH Futures, and ARK Invest; brokerage firms like Coinbase's L2 network; NFT loyalty programs like that offered by Adidas ALTS; and games like Zynga's "Sugartown." As traditional companies implement new business models and

cost reduction strategies in Web3, the technology is poised to have an impact as significant as cloud infrastructure in the 2010s.

This is the beginning of Web3's era of institutional adoption, as major criticisms of public blockchain technology around energy utilization and scalability continue to weaken. Expect to see continued development and deployment of Web3 initiatives from companies across every industry; the companies experimenting with the technology now will have a leg up on competition in the future.

Adidas ALTS are NFTs that provide early access to virtual and physical products.

Image credit: Adidas

SCENARIOS

What If SEC lawsuits were successful?

"US Falls Behind in Fintech as SEC Wins Major Crypto Lawsuits"

In a landmark development, the US Securities and Exchange Commission has successfully sued major crypto entities including Binance, Coinbase, DAOs, stablecoins, and NFT projects. This crackdown has driven crypto projects out of the US, severely limiting American access to the crypto markets and crippling related businesses. The SEC's aggressive stance has effectively severed the on-ramps for US citizens to crypto markets and reversed the country's fortune in the crypto industry, once boosted by China's crypto ban.

This shift has left the US lagging in fintech innovation. Now, regions like Japan, the EU, and Africa are emerging as new fintech leaders, capitalizing on the exodus of blockchain expertise from the US. The departure of blockchain projects has led to a dearth of skilled professionals in the field. US investors face minimal protection, as they can still access offshore protocols without oversight, echoing the FTX collapse in the Bahamas. Japan, in particular, is rising as an economic powerhouse due to its alignment with the Web3 industry and supportive regulatory environment. Meanwhile, the growth of DeFi and other blockchain projects is expected to slow, especially with US users facing access barriers.

The upcoming Supreme Court decision on defining investment contracts could further shape the SEC's reach over stablecoins and DeFi. As the global blockchain business adapts, the US' once-dominant position in fintech innovation is now challenged, marking a significant shift in the landscape of financial technology.

WEB3 INFRASTRUCTURE

WEB3 INFRASTRUCTURE

Proof of Stake Proves Its Worth

Ethereum's 2022 transition from electricity-guzzling proof of work (PoW) to a more energy-efficient and decentralized network secured by proof of stake was an incredible feat. But it's only a stepping stone in the progression toward a hyper-scalable, fully decentralized, highly secure, and easily usable platform for the internet.

Now, the Ethereum community has a list of improvement proposals, and research is ongoing to improve each area. They include adding temporary data storage to enhance the scalability of Layer 2 chains, increasing decentralization by separating block proposer and block builder capabilities to strip out MEV bots' capabilities to censor transactions, and improving account abstraction.

While none of the proposals or areas of research have hard implementation timelines, the Ethereum community has a proven track record of delivering high-quality and thoroughly tested protocol updates. Companies still on the Web3 sidelines because they lack technical capability or fear usability issues should observe these behind-the-scenes moves; these new developments will continue to improve the capabilities of the platform for all types of applications.

Emerging Forms of Consensus Protocols

By many measures, Ethereum's merge to proof of stake (PoS) was a great success: The transition went smoothly, energy consumption dropped by 99%, staked ETH that secures the network has increased every month since the merge, and many more Ethereum users can participate in securing the network. But while PoS is a mainstay consensus mechanism in Web3, Ethereum's PoS is not a one-size-fits-all approach and still has downsides, such as limited scalability.

Other networks have chosen different forms of consensus protocols. Filecoin, a decentralized storage blockchain network, uses two different types of consensus mechanisms that allow the nodes in the network to verify data has been stored and continues to be stored in the network. This may become increasingly important for specialized chains, which may need to change underlying infrastructure to bring new capabilities to the blockchain ecosystem.

Another recurring theme is new alternative Layer 1 blockchains. Most recently Aptos and Sui, two heavily venture-backed L1s, deployed their mainnets and are attempting to wrestle network usage away from incumbents like Ethereum and Solana with tech stack upgrades. They both use PoS but have very different algorithms under the hood: They're now using a two-pronged approach to transaction consensus that allows for high scalability through parallelizing transactions.

These protocols weren't possible in Ethereum's PoS based on how the blocks are structured and could present a red flag for the company. Ethereum's technology has lagged behind the industry for many years, but its massive network effects keep it relevant. Time will tell if a younger blockchain with more innovative consensus mechanisms and infrastructure designs can outcompete the current platform of choice.

Blockchain Modularity

The "blockchain trilemma" highlights a key challenge in Layer 1 blockchains: Optimizing for scalability, decentralization, and security simultaneously is difficult. Ethereum excels in decentralization and security but lags in scalability, while Solana offers scalability and security but compromises on decentralization. To address this, the blockchain sector is turning to modularity, separating Layer 1 blockchain functions—execution, settlement, consensus, and data availability—into distinct, specialized chains.

This approach is evident in Ethereum's Layer 2 solutions like Optimistic and Zero Knowledge Rollups, which enhance transaction speed and cost-efficiency. More broadly, various Layer 2s and blockchains are experimenting with different module combinations, aiming to improve blockchain performance and interconnect ecosystems. A notable example is Eclipse, a new Layer 2 architecture that integrates Ethereum, Celestia, Solana, and RISC Zero for different functionalities, showcasing advanced modularity.

WEB3 INFRASTRUCTURE

Although still in its early stages, the modular blockchain concept is gaining traction. The uptake of existing Layer 2 solutions and on-going experiments in specialized chains suggest a future where modular strategies could be vital in solving the blockchain trilemma for diverse applications and business needs.

Zero-Knowledge Proofs

Zero-knowledge proofs (ZKPs) aren't new: They were theorized back in the 1980s by researchers at New York University and were first deployed at scale with the 2016 launch of ZCash, a privacy-focused cryptocurrency based on bitcoin's codebase. More recently, improvements to computational capabilities and the cryptography itself have allowed for wider-scale deployment of ZKPs in the crypto space, most notably with ZK-Rollups.

ZKPs have gained significant adoption due to their two core characteristics: succinctness and privacy. The succinctness characteristic is the basis for the scalability enhancements of ZK-Rollups, because nodes can compute proofs of transactions off-chain and submit the proofs to Layer 1 for verification. This shifts the heavy computation off-chain while still verifying the validity of every transaction.

However, ZKP characteristics allow them to be applied far beyond blockchain scalability solutions: Researchers are studying the application of ZKPs to AI training, interaction, and verification of model outputs. As computation capacity continues to increase and ZKP technology improves, expect to see it used throughout digital interactions to provide great control over private data and decrease unverified or fraudulent information.

The Appchain Thesis on Ethereum

The Appchain concept, originated by Cosmos, has been adopted in Ethereum's Layer 2 (L2) ecosystem. This idea advocates for protocols to create their own independent chains when they grow significantly, ensuring full control and reducing reliance on their original blockchain. RollApps, a key L2 provider, facilitates this by offering tools for easy deployment of new chains.

Ethereum's L2 chains like Arbitrum, Optimism, and zkSync are embracing this approach, allowing easier creation of L2 and L3 chains. These solutions enhance deployment ease, and upgrade flexibility, interoperability, and scalability, although Cosmos was the first to introduce this model. Coinbase's Base is another example of this trend, built on the Optimism OP Stack. Its success may prompt other companies to explore similar solutions.

This shift is crucial as it enhances scalability and reduces costs, making blockchain more user-friendly, especially for high-transaction applications. Application-specific chains offer more specialization and the possibility of private chains within a decentralized network, believed to be key for future interoperability and simplified user experience. However, not all in the crypto community agree with the multichain approach of Appchain. Some, like Solana, focus on a single chain for all applications. The effectiveness of these diverse strategies will become clearer over time.

WEB3 INFRASTRUCTURE

Data-as-a-Problem

Data storage, now cheaper and faster in the traditional economy, is a problem for blockchains. Their unique design, which limits how much data can be stored in blocks, makes data storage costly and challenging to optimize.

A key issue for blockchain scalability is the block size and the hardware needed to process and validate data. Bigger blocks are more scalable but require more computational power, making them expensive for validators and potentially reducing decentralization. Solutions like sharding or modularity can help blockchains circumvent these hardware demands, but they face the data availability problem, where malicious nodes could hide crucial transaction data. So, light nodes need methods to verify data availability without downloading everything, maintaining the efficiency of sharding.

Developers are seeking solutions to these challenges. PayPal sought a patent to prune blockchain blocks and store them with a data storage provider. Ethereum is set to introduce EIP-4844 (proto-danksharding), adding a new, less resource-intensive data section to blocks, called "blobs," to ease the computational load on nodes and improve scalability. Other projects are exploring approaches like data hosting consortiums and modular blockchain designs. Further progress from various crypto market segments should enhance scalability without compromising decentralization or security.

DECENTRALIZED APPLICATIONS

DECENTRALIZED APPLICATIONS

DeFi Protocols Network Effects

DeFi protocol business models are traditional: Protocols provide products and services and generate fees distributed to stakeholders. But these protocols operate in a unique environment: The business's "secret sauce" is public knowledge because nearly all DeFi protocols are open source.

Open-source protocols can generate competition—Uniswap has forked nearly 500 times, spurring continuous innovation—but they can also splinter the market and provide an opening for fraudulent activity. This was the case with Compounder Finance, a fork of Yearn Finance that scammed investors out of more than $10 million with minimal development effort.

Fraudulent projects are still a concern, but the bear market has washed out smaller competitors as investors leave the market or flee to more reputable service providers. As a result, large DeFi protocols continue to expand their influence, both vertically to provide more DeFi services (such as Maker starting

as a stablecoin provider but expanding into lending as Spark Protocol) and horizontally to provide the same services across multiple chains (such as Aave's lending product being available across nine different blockchains).

The average user can't verify code and will likely gravitate toward protocols with the best reputations. At the same time, businesses will have robust and tested codebases to use and adapt to their own chain services.

Guerilla Marketing: Crypto Airdrops

Airdrops raise awareness, drive user adoption, stress test platforms, and reward active or long-time users. They can be extremely lucrative: NFT platform Blur distributed tokens as part of its multiseason airdrop program, and in the first season, 23 users earned more than $1 million in tokens.

Still, platforms should weigh benefits against long-term goals. If airdrops are too short term or have misaligned incentives,

they can miss the mark of getting real user adoption. Users have learned to game airdrop programs, known as "airdrop farming," where users set up dozens of automated wallets programmed to maximize their chances and total rewards from an airdrop. Incentive structure and qualifications for airdrops can limit this behavior, but many platforms have struggled. Arbitrum, a leading Ethereum L2, had a significant issue with airdrop farming that left many retail users dissatisfied, and to this day, 72 million ARB tokens are unclaimed.

While Arbitrum has become extremely successful anyway, the viability of these programs is murky. Most, if not all, tokens with significant airdrops see massive sell-offs at token distribution, as many users dump tokens to lock in value. It's difficult to tell if these users eventually return to the platform. But even if the outcomes are unclear, airdrops have become a mainstay in the ecosystem as a significant hype generator.

Hyperfinancialization

Financialization has been a hot-button topic in the crypto market as goods typically not considered financial assets—such as art, video games, and social media—are commoditized, recasting their value from enjoyment to investment returns.

In art, advanced trading techniques like mass NFT buys and sells commoditized art and shifts the focus away from culture and community. At the same time, token incentives spurred the gamification of NFT trades and manipulated volumes. The financialization of video games, GameFi (the combination of decentralized finance and video games) is often criticized for its lack of engaging gameplay and a hyper-focus on financialization. The latest development in social media financialization—Friend.tech—is also controversial. It allows users to tokenize social connections on X by buying and selling a sort of "key" in public profiles that gives access to private chat rooms and is criticized for commodifying people through their social media accounts.

DECENTRALIZED APPLICATIONS

In each case, the implementation and degree of financialization seems to be extremely important in the outcomes of the application. Despite the criticisms, financialization remains a core tenet of the crypto ecosystem. Expect to see new applications of financialization continue to be developed with ensuing volatility and uncertainty.

Personal "X-As-A-Service" Earning Models

Web3 has opened the door for consumers to earn through "X-as-a-service" models that allow for the automation of personal hardware and digital assets to generate returns—particularly in computation, security, and utility.

As mining is now monopolized by professional outfits, users seeking to provide computation-as-a-service are pivoting to running millions of iterations of training data for AI models—and getting paid handsomely for it. In Security-as-a-Service, blockchain users can stake their tokens to participate in transaction and block validation, helping secure the network. In the same area, restaking is

a new blockchain primitive where staked token balances on Ethereum can be used to validate Ethereum and other chains simultaneously for juicier yields. In NFT gaming projects, users can provide utility-as-a-service by providing digital services to player bases and earning portions of the transactions on their digital properties.

There are many more as-a-service earning opportunities for crypto adopters, such as providing liquidity as a service on DeFi platforms or providing cloud storage on Filecoin's IPFS network. Many of these opportunities are limited to those with the knowledge and technical abilities to navigate the crypto ecosystem. Still, as barriers to adoption come down, these earning models will be available to anyone with internet access.

Crypto miner Hut 8 invested in five data centers which can now be used for other purposes, including training AI.

Image credit: Coindesk

SCENARIOS

What If We Established Systemically Important Technology Institutions (SITIs)?

The global financial system has undergone a transformation, with technology companies at its core. Over the past two decades, as digital assets have taken over, technology companies have invested heavily, by developing digital wallets, cryptocurrency exchanges, and NFT marketplaces, making these services integral to their digital ecosystems.

As a result, following a recent meeting, the US Financial Stability Oversight Council (FSOC) has announced plans to designate certain technology companies as being systematically important: a significant departure from the definition of "systemically important institutions" portrayed in the 2010 Dodd-Frank Act.

This oversight regulates technology organizations that now steward most of the country's digital assets, which have become the underpinning of economic value. Digital assets have ballooned in value due to the financialization and monetization of people's digital identities, capabilities, and online followings, as well as the tokenization of physical assets such as homes and vehicles. While blockchain technology spurred the creation of digital assets and ease of transacting online, adoption hurdled around technical requirements, leaving oversight, self-custody, and security concerns to be solved.

Systemically Important Technology Institutions (SITIs) will be required to adhere to strict standards in financial stability and risk management. They must also comply with advanced cybersecurity measures to protect against potential threats. This increased burden of compliance will weigh heavily on some technology companies but will at last secure the new economy of digital assets that many have come to rely on.

WEB2 & WEB3 INTEGRATION

WEB2 & WEB3 INTEGRATION

Digital Content Provenance and Authentication

As more and more platforms adopt AI, it becomes increasingly important for users to be able to verify the origin and authenticity of digital content. C2PA, the coalition of major tech companies founded in 2020 looking to develop an open-source infrastructure to protect digital content and consumers from fake news, has seen its membership increase by 60% over the past year due to interest in AI.

Digital watermarking can help human content creators by marking human content that's used in AI training to make sure it doesn't run afoul of copyright laws. In contrast, cryptographic hash functions that track and store the data manipulation history of assets can help human consumers. Zero-knowledge proofs can also help authenticate AI output by providing a model with certain conditions without revealing how the model created the output. Of course, in the future, as AIs start to be involved in higher-stakes decisions, there will be more incentives to tamper with or replace the model. Modulus Labs is experimenting with chain AI deployments for high visibility and easy verification of model outputs.

While progress has been swift, larger strides are necessary to get these technologies deployed at scale to protect consumers from malicious and false information and content creators' ownership of their digital content.
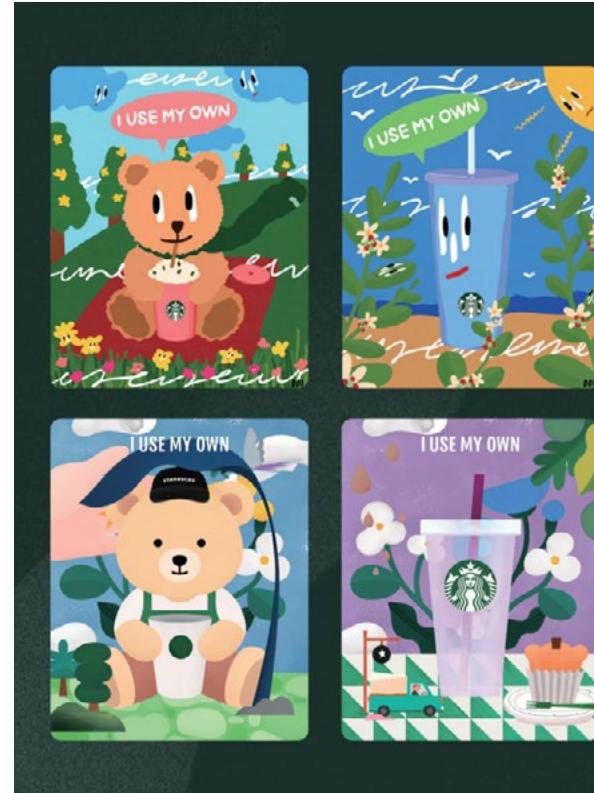
NFTs: Beyond the JPEG

When NFTs hit the mainstream, they focused on JPEG art. While this made NFTs a household term, the technology's ease of transfer, easy verification, historical ownership tracking, and immutability have benefits beyond pictures-for-profiles. Now, NFTs are being deployed to digitize ownership of assets in the real estate industry, make event ticketing more secure, and augment retailers' loyalty programs.

Consumer-facing companies are entering Web3 with NFTs at the core of their strategy: Nike, Starbucks, and Ducati have NFT programs that bridge the gap between their physical and digital products. Puma and NBA player LaMelo Ball partnered with Open Sea and Gutter Cat Gang to sell NFT versions of a sneaker release that are convertible into a physical part of shoes once they're produced. ALTS by Adidas offer NFTs with perks for holders, like exclusive access to drops.

Web2 and Web3 native NFT projects are also converging. Blue-chip NFT projects like Doodles and Pudgy Penguins have launched clothing and toy lines, and Nouns DAO funded a full-length movie featuring popular NFT characters. Even if NFT trading markets never return to the highs they reached in 2021 and 2022, the technology is helping businesses and projects acquire, develop, collaborate with, and monetize a deeper connection with communities.

Starbucks launched an NFT project in Korea called 'Starbucks Starlight' which encourages customers to use their own cups.

Image Credit: Starbucks

WEB2 & WEB3 INTEGRATION

Self-Sovereign Identity Solutions

Growing online interactions dramatically increase the data people share with third parties. While centralized providers like Google and Facebook make it easy to sign in with one click, this enables tracking and puts consumer data at significant risk. In response, organizations like The Linux Foundation, W3C, and the Decentralized Identity Foundation have developed software standards that allow users to manage access to their data.

Self-sovereign identity (SSI) digitizes identity, giving data owners control of their digital identities, enabling access to digital ecosystems, and giving users control over what details of their identity are shared with different parties. While SSI has no set standard, it typically combines distributed ledger technology and cryptography with verifiable credentials and decentralized identifiers. SSI could reduce data breaches, as companies no longer need to store personal information.

Players like J.P. Morgan, Workday, and Microsoft have decentralized ID projects, but adoption has been slow, likely because of the lack of profit incentives and consumer visibility. However, US and EU government agencies are offering grants and installing mandates to allow decentralized identity solutions to be built into consumer-facing wallets. In the EU, decentralized identity wallets are expected to launch as part of its 2030 Digital Decade program next year.
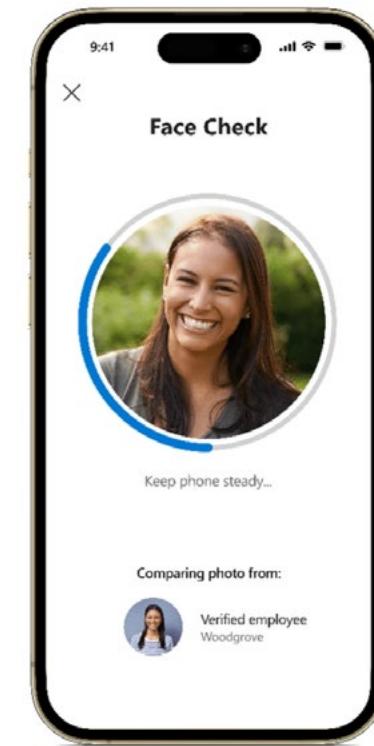
Tokenization of TradFi, Digital Assets & Security Tokens

The tokenization of real-world assets—security tokens—has been a bright spot in blockchain development. So far, security tokens have had limited implementation. One exception is Japan, which already has a thriving security token market focused on tokenizing corporate bonds or real estate–backed securities.

Growth is on the horizon: More organizations are adopting security tokens, more jurisdictions offer regulatory clarity, and bond market yields are increasing. The industry is experiencing two trajectories of security tokens: tokenization that occurs in closed or private blockchain networks and that which is underway in public blockchain networks. On private blockchains, companies like Citigroup and Goldman Sachs are experimenting with tokenized digital securities markets to facilitate faster and more efficient financial services. On the public blockchain, US government bonds have been tokenized—Maker, Tether, and USDC use US treasuries as collateral.

Another area of development is in the tokenization of physical collectibles. In September, Arcade.xyz, a protocol specializing in peer-to-peer loans, facilitated a $1.1 million loan where an NFT of a Supreme T-shirt collection was used as collateral. Many prominent figures and consulting firms see the tokenization of assets as a potential multitrillion-dollar market for blockchain technology.

Microsoft launched Entra Verified ID in early 2024 to include Face Check, a facial matching feature.

Image credit: Microsoft

WEB2 & WEB3 INTEGRATION

Credibility Scoring and Anonymity

DeFi lending is not capital efficient: Most DeFi loans are overcollateralized. To fix that balance, lending companies are turning to conventional means of credit risk scoring using on-chain data and nontraditional metrics focusing on reputational scoring of addresses based on DeFi activity.

Companies like Spectral pull on-chain data for accounts and use AI algorithms to analyze lending, borrowing, and other history and output a credit score. Other protocols like Taraxa and Cred Protocol use a mixture of on-chain and off-chain reputational metrics to enhance score outputs. DeFi is also using off-chain credit scores, like those reported by TransUnion. The company's partnership with Web3 companies Quadrata and Spring Labs allows users to port their credit scores directly into DeFi applications.

While credit scores improve capital efficiency, attaching scores to blockchain reduces user anonymity, a core tenant of the technology. The range of impact depends on the solution:

On-chain credit calculations have a lower risk, but blending on- and off-chain data will at a minimum result in pseudonyms. Off-chain credit scores will tie directly to individual identities. This could be a significant deterrent for crypto natives for whom anonymity is crucial. Still, for the next wave of adopters who are used to standard identity verification, it may have less impact.

On-Chain Gaming: Play, Own, Earn & Enjoy

On-chain games incorporate blockchain technology, ranging from fully on-chain games to those that only have digital assets on-chain. Fully on-chain games have all the benefits of blockchain, including alternative funding, community development, decentralized serverless development, player ownership, composability, and player-driven economies.

While the benefits of on-chain gaming are attractive, game deployments are subject to current capacity constraints of public blockchains. This has resulted in the release of initially slow turn-based games involving trading cards or battles that were criticized

for their lack of fun. These days, blockchain advancements in scalability and usability have enabled developers to create AA and AAA titles. Game studios such as Star Atlas, Gala Games, Bright Star, and others are deep into developing such games.

Traditional gaming companies have hesitated to adopt blockchain. Still, companies like Zynga and Ubisoft are experimenting with on-chain games—most notably Zynga's "Sugartown." It's built on Ethereum and just dropped an NFT collection tied to the project. Zynga has a history of producing high-quality hits, and the game's success could pave the way for users' increased familiarity with on-chain assets, tokens, and staking. This could in turn lead to increased Web3 integration and game development in the future.

Sugartown is a Web3 gaming platform created by Zynga.

Image Credit: Zynga

SCENARIOS

What If We Used AI To Monetize Privacy?

Are you tired of feeling like your personal data is out of your control? Well now you can rest easy with DataSentinel. This game-changing protection in digital privacy and data control is powered by AI, and purpose-built to keep you safe. Imagine a world where you are the master of your data. With DataSentinel, that world is now a reality. DataSentinel's cutting-edge self-sovereign identity solutions keep your private data stored securely and decentralized—meaning you, and only you, have the keys to your digital kingdom.

Here's the best part: With DataSentinel, you can monetize your data. That's right, turn your data into dollars! DataSentinel's AI-powered system optimizes your data, making it valuable for companies willing to pay for your insights. It's time your data started working for you!

The security on DataSentinel is top-notch. Thanks to blockchain technology, your personal information is safe and sound. Plus, you have the power to grant or revoke access as you see fit. It's like having a digital bodyguard. Gone are the days when companies could exploit your data without your consent. With DataSentinel, you forge a new path in the digital world, one where privacy isn't just a feature—it's a right.

Let's not forget about convenience! DataSentinel models are like personal assistants for your digital life, handling everything with the utmost confidentiality and efficiency. In compliance with the strictest data privacy regulations, DataSentinel ensures you're always in the driver's seat of your digital identity. So, if you're ready to take control of your digital life, sign up for DataSentinel and join the digital revolution. Your data will thank you!

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METAVERSE · NEW REALITIES

Future Today Institute

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TOP HEADLINES

The metaverse sees a cooldown from its initial hype, marking a phase of recalibration and more realistic expectations.

01 **Meta and Apple Impress with New VR Hand Tracking and Gesture Recognition**

The tech giants' latest headsets showcase hand tracking and gesture recognition capabilities offering users a more intuitive way to interact with virtual environments.

02 **Events in the Metaverse Flop**

Metaverse Fashion Week saw major brands invest but drew few visitors, who found it lonely and dull. Substantial investment and creativity are needed to boost engagement.

03 **Metaverse Layoffs: Meta and Disney Scale Back Amid Cooling Hype**

As the initial excitement around the metaverse wanes, Meta reduced its workforce, and Disney shut down its division dedicated to exploring metaverse opportunities, signaling a reset in the industry's approach.

04 **Deepfakes Emerge as a Concern Ahead of Election Cycle**

While some are entertainment, the technology's potential for fabricating hyperrealistic news and political footage to deceive voters is alarming ahead of upcoming elections. Experts worry viral deepfakes could spread misinformation across social media.

05 **Early Adopters Explore Digital Twins for the Enterprise**

Innovative early adopters in sectors like autonomous vehicles and smart cities are looking into the potential of digital twins.

STATE OF PLAY

Overshadowed by the rise of artificial intelligence, the metaverse is searching for new potential through AI integration, evolving from initial hype to a measured and mature future.

When Facebook rebranded as Meta in 2021, it bet big on leading the next computing platform—the metaverse. However, early criticisms emerged, given the rudimentary state of virtual and augmented reality (AR) technology at the time, with many clunky headsets and cartoonish avatars. The spotlight soon shifted when OpenAI unveiled ChatGPT in 2022, captivating public interest in AI. Unlike past AI systems, ChatGPT's accessibility enabled mainstream user interaction for the first time, representing a key inflection point. This overshadowed enthusiasm for the metaverse, which was having adoption challenges. Disney retreated on its own metaverse goals amid disillusionment, and Meta's Reality Labs posted a staggering $13.7 billion loss in 2022.

Yet in 2023, major tech players recognized the potential in fusing AI and metaverse technologies to take immersive simulations to the next level. Meta CEO Mark Zuckerberg unveiled strikingly realistic virtual avatars, enabled by AI—a major leap in simulation quality. Microsoft shared plans to blend its AI Copilot with HoloLens 2, delivering an AR experience for workers. And Apple introduced Vision Pro, a spatial computing headset employing machine learning for more natural user interactions. Rather than competing trends, AI and the metaverse now appear poised to complement each other. The future points to AI-enabled metaverse experiences that feel increasingly personalized by learning user preferences.

Meta also unveiled more subtle technologies like smart glasses, signaling a shift in consumer preferences for extended reality (XR) technologies that integrate digital experiences with physical reality. In doing so, these technologies could enhance human connection, as the technical interface fades into the background, replacing screen-centric interactions with more natural, human-centered ones. Spaces and the nature of work could be transformed, reducing our reliance on traditional screens and keyboards, and potentially revolutionizing the built environment and our interactions with computers. The form factor of XR technology could evolve to where our natural actions and environments become the primary means of interaction, ushering in a new era of computing that is more integrated with daily life. This evolution mirrors AI advancements in natural language, enabling more intuitive metaverse interactions.

In many ways, the trajectories of AI and the metaverse have come full circle. What began as separate trends with muted enthusiasm has given way to recognition of their interdependence in creating more immersive digital interactions. Their futures are now fundamentally linked, with advances in one enabling progress in the other.

KEY EVENTS

FEBRUARY 1, 2023

A Long-Term Vision is Challenged
Meta's Reality Labs division, specializing in AR and VR technologies, reports significant operating losses of $13.7 billion for 2022.

OCTOBER 23, 2023

Saudi Cities Embrace Digital Twins
South Korea's Naver wins a $100 million deal to create digital twins for five Saudi cities, enhancing urban planning and flood management.

FEBRUARY 2, 2024

Apple Vision Pro is Released
Apple released its newest mixed reality headset with over 600 apps, video passthrough, and spatial audio.

SEPTEMBER 28, 2023

Meta Town Hall Highlights AR
Mark Zuckerberg showcases Ray-Ban smart glasses as key to Meta's subtle, stylish AR shift. Shortly after, Meta Quest 3 debuts, offering advanced mixed reality experiences but garners mixed reviews and slow adoption.

NOVEMBER 15, 2023

Metaverse Medical Market
Ocutrx's OcuLenz AR headset, designed for macular degeneration, highlights medical applications as a key path for AR technology adoption beyond entertainment.

LIKELY NEAR TERM DEVELOPMENTS

THE FOUNDATIONS OF THE METAVERSE

As virtual experiences become more embedded into daily life, we can expect growing pains. Regulators must balance guidelines that ensure integrity without restricting an nascent industry. Tapid advances precipitate more seamless, intuitive user experiences. Hands-free environments feel within reach as innovations like gesture control tech remove friction. Past the hype, enterprise use cases will gain traction, and efficiency gains will drive adoption beyond novelty appeal. Generative AI will further accelerate proliferation by enabling amateur creators to construct fully realized 3D worlds without coding skills. With increased adoption, interoperability will rise as a priority. Metaverse technology has perpetually searched for a wide audience—if it fails to reach the mainstream consumer, industrial use cases may take over. Medical, industrial, or civic metaverses may be the first to find product-market fit. Their focused nature could lend itself more readily to creating utility and value.

Completely Hands-Free Experience

As delivery routes and last-mile deliveries continue to increase in speed and complexity, automation will let logistics companies create an intricate web of delivery offerings that can be unique to each customer.

Metaverse-Tailored Offerings

As climate change continues to be a disruption, logistics providers will explore how they can insure against extreme weather events. These costs could be passed along to consumers who choose goods from more volatile regions.

Metaverse World Building for All

Increased automation and use of virtual agents raise the need for workers to know how to manage new tech-enabled work and tasks. This upskilling could be done through remote learning and working opportunities.

Extended Reality Gets Serious

With workers continuing to grow in scarcity, virtual agents will take over back-of-house work in the warehouse. These virtual agents will soon be able to oversee themselves and their cobot workers, reducing the need for human intervention.

Regulators Target Virtual Trading

With manufacturing locations moving closer to the consumer and e-commerce increasing, manufacturers need to consider how to create products in the exact spot as their consumers.

Consumer Push for Interoperability

Global conflicts, combined with consumers and businesses wary of supporting governments with values antithetical to their own will increase demand for verification of supply chains. Granular data collection and transmission will enable this shift in transparency.

11 MACRO SOURCES OF DISRUPTION
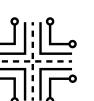
| Technology | Media & Telecom | Demographics | Environment | Government | Public Health | Education | Geopolitics | Infrastructure | Economy | Wealth Distribution |

WHY METAVERSE & NEW REALITIES TRENDS MATTER TO YOUR ORGANIZATION

Avatars Enable Personalization But Fragment Identity

Hyperrealistic avatars will enable more personalized brand experiences, but consumer identity may fragment across multiple avatars tailored to different contexts. This complicates marketing analysis, as brands must derive insights from fragmented consumer journeys and understand core motivations persisting across digital identities.

Digital Twins Save Time, Money, and Reduce Risk

Digital twins will revolutionize enterprise operations by enabling virtual prototyping, testing, and optimizing. Companies can digitally iterate designs and stress test ideas for better quality, gaining a competitive edge in market speed while minimizing downtime and disruption. By saving money and managing risk, this shift to virtual environments will drive innovation.

The Dual Edge of Hyperrealistic Avatars

Hyperrealistic avatars offer brands detailed customer insights but risk misuse. They enable lifelike interactions and richer data while supporting a deeper understanding of target demographics. However, the potential for deepfakes makes identity validation a challenge and puts brand reputations at risk. The ability to trust the accuracy of avatar identities will be critical for ensuring messaging reaches intended audiences.

Metaverse Unlocks Immersive Marketing Avenues

Immersive virtual worlds offer a new frontier for brand marketing. In the metaverse, brands can engage customers through lifelike, personalized interactions, blending products and messages into the virtual cultural fabric. This narrative-based approach boosts virality and peer sharing, while rich data informs strategy and product development. Substantial investment in creative talent and technology is essential for establishing top-tier experiences.

Safely Mastering High-Risk Skills
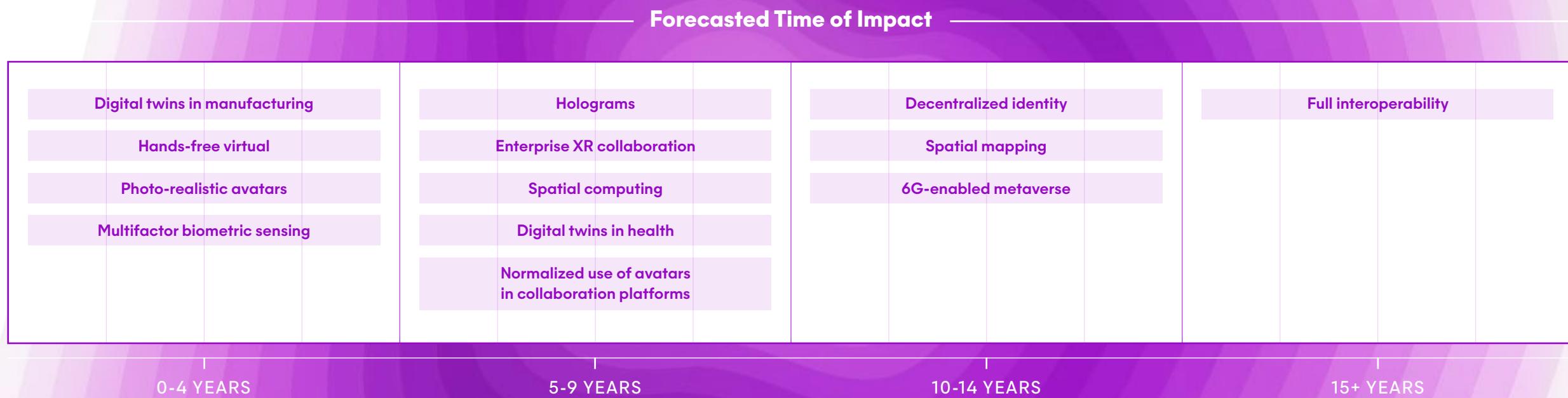
XR in enterprise training rapidly upskills employees' safely, even in high-risk areas. Realistic simulations for tasks like operating machinery or handling emergencies build skills and confidence without real-world risks. This leads to a workforce adept at complex jobs, reducing mistakes. XR training offers quicker proficiency, lower risk, and no need for physical practice, optimizing talent development and shortening onboarding.

Early XR Adoption Boosts Workforce Dynamics

Augmented reality could reduce reliance on screens, minimizing screen fatigue and enabling more natural human-computer collaboration. Spatial overlays could also optimize workflows by aligning virtual models with physical spaces. As XR advances, traditional seated desk work may transition to immersive environments centered on voice and gestures rather than mouse clicks. Built spaces could be reimagined, reducing fixed real estate costs and promising more ergonomic, satisfying, and dynamic work routines with less dependence on screens.

WHEN WILL THE METAVERSE & NEW REALITIES DISRUPT YOUR ORGANIZATION?

Forecasted Time of Impact

0-4 YEARS	5-9 YEARS	10-14 YEARS	15+ YEARS
Digital twins in manufacturing	Holograms	Decentralized identity	Full interoperability
Hands-free virtual	Enterprise XR collaboration	Spatial mapping	
Photo-realistic avatars	Spatial computing	6G-enabled metaverse	
Multifactor biometric sensing	Digital twins in health		
	Normalized use of avatars in collaboration platforms		

OPPORTUNITIES & THREATS

Threats

The lack of asset and avatar portability across platforms like Meta Horizon or Microsoft Mesh limits the metaverse's potential and user experience. The inability to transfer digital assets across different metaverse platforms creates a fragmented and restrictive environment.

There is significant risk in prioritizing proprietary control, and those seeking walled-garden dominance risk stunted growth. If standardized protocols are not developed as they were for the internet, the metaverse's vision may not be actualized and it will be a flop.

The advancement of synthetic media has given rise to substantial ethical challenges, particularly around the issue of consent. Both public figures and private individuals face the prospect of their likenesses being replicated without permission, prompting serious concerns about autonomy and control over digital identities.

The creation of digital replicas raises philosophical questions about the authenticity of human expression and the ethical implications of creating and interacting with digital beings that mimic real individuals.

The metaverse could exacerbate isolation and detachment from reality. The lack of physical human interaction could diminish the quality of real-world relationships, leading to feelings of loneliness and disconnection.

Opportunities

Digital twins can serve as powerful tools for testing, optimizing, and making more informed decisions in a controlled setting. They help with proactive maintenance, predicting failures before they occur, and reducing downtime.

Metaverse marketing could bring brands closer to consumers and influencers closer to their followers. It enables interactive spaces for community building so users can interact not only with the brand but also with each other, enhancing loyalty and engagement.

Virtual training offers efficient skill development in low-risk environments, improving employee competencies and safety. Trainees can experience realistic scenarios without the dangers associated with real-life training, and it reduces the need for physical resources, travel, and on-site training facilities.

With companies integrating metaverse capabilities into platforms like Teams, remote collaboration is becoming more effective. Enhanced AI translations and the metaverse's elimination of geographical constraints means global teams can overcome language and distance barriers to access talent.

The companies that contribute most meaningfully to open standards and standardized protocols will emerge as long-term winners. By building compatibility across platforms, these companies can expand their reach, enabling their products to seamlessly integrate with a range of metaverse environments and tools.

INVESTMENTS AND ACTIONS TO CONSIDER

1

Pursue novel brand interactions. Rather than mirroring real-world marketing in virtual spaces, explore novel modalities unique to these mediums. Provide value via exclusive metaverse experiences that offer intimacy at scale. Stay atop innovations in synthetic media and immersive technologies to remain cutting-edge.

2

Get ahead of unintended consequences. Monitor early metaverse adopters across functions for potential psycho-social impacts, and implement support systems proactively, like VR-based counseling or hybrid work policies. Navigate this responsibility wisely.

3

Spearhead industry interoperability standards. Get ahead of fragmentation by convening an industry consortium to align on metaverse interoperability standards early. Prioritize user portability and platform connectivity. Lead here before ecosystems splinter and momentum makes alignment difficult.

4

Use immersive training for risk mitigation. Leverage XR for disaster preparedness, hazardous environment rehearsals, and other high-risk training needs. Repeatable virtual drills identify gaps efficiently at lower risk and cost than live exercises.

5

Differentiate with digital previews. Build 3D virtual models of spaces to allow remote previews and walk-throughs. For real estate, this enables global property tours. Hotels and venues can offer virtual site visits to event planners. Unique visibility and accessibility become a competitive edge.

6

Accelerate development cycles. Construct digital prototypes of products early in the design process for rapid iteration and user testing in VR. Refine designs, materials, and interactions before physical production. Democratize innovation by extending tools to customers.

CENTRAL THEMES

The Quest for Connection

There is a nuanced interplay between digital immersion and the desire to maintain a connection with the physical world. Consumers increasingly show a preference for augmented reality over virtual reality, indicating a broader inclination toward digital experiences that complement, rather than replace, the physical environment. The social dimension of the metaverse is equally critical. For the metaverse to be genuinely transformative, it needs to enhance social connections rather than create isolation. Its success will largely depend on its ability to foster genuine human interaction and community building. However, this new digital frontier is also reshaping social dynamics in profound ways. For instance, the increasing use of devices like smart glasses, which can record interactions, introduces a new dynamic in social behavior. People may modify their behavior, knowing they could be recorded at any time, affecting the authenticity of social exchanges. In essence, the metaverse is not just a technological space but a social one, heavily influenced by human behavior and societal norms.

The Technological Symphony of the Metaverse

The metaverse stands as a technological apex, relying on the culmination and integration of various advanced technologies still in development. Its realization hinges on the progress of numerous fields, including powerful battery technology, enhanced connectivity and the widespread deployment of 5G, as well as the evolution of wearable devices. This convergence suggests that the idealize vision of the metaverse is not just an isolated development but rather the endpoint of numerous technological trajectories. These include significant advancements in computing power, sophisticated AI algorithms, and innovations in the entertainment sector, all of which are crucial in shaping an immersive, seamless, and interactive metaverse experience. As such, the journey toward the fully realized metaverse is as much about the progression of these individual technologies as it is about their harmonious integration.

AI: Not Parallel But Key to Actualizing the Metaverse

AI is not just an accompanying technology in the development of the metaverse; it is a critical driver making the metaverse's existence and functionality possible. For instance, a key contribution of AI in the metaverse is the enhancement of user interactions through advanced natural language processing. This technology allows for more natural and intuitive communication within virtual environments, making interactions with AI-driven avatars and interfaces more fluid and life-like. Moreover, AI facilitates the creation of expansive, complex virtual worlds. It enables the rendering of highly detailed and dynamic environments, which can adapt and respond to user interactions in real time. Additionally, AI contributes to the personalization of experiences within the metaverse. By analyzing user data and behavior, AI can tailor experiences to individual preferences. This customization capability will be necessary for making the metaverse less like a generic virtual space and one that feels uniquely relevant to each user.

CENTRAL THEMES

The Invisible Interface

An overarching drive toward more natural interactions underscores a key vision emerging for the metaverse. For input, companies like Meta, Apple, and Snap are developing innovations in voice control, hand gestures, and even neural signals that interpret eye and facial muscle movements. These updates remove the need for traditional physical controls, aligning with a frontier of silent, seamless interaction powered by AI. Gesture technology is advancing rapidly, pointing to hands-free experiences. Neural signals take this even further by tapping directly into biological cues to enable control through cognition alone. For output, advances in haptics and multisensory technologies point to a future beyond visuals and audio, where virtual experiences feel increasingly tactile and lifelike. The emergence of these subtle, intuitive technologies reveals we are slowly starting to actualize one vision of the metaverse: for the interface between humans and technology to fade into the background, becoming almost invisible.

Fragmented Realities

While individual companies are making strides developing their own metaverse platforms and capabilities, true interoperability across these disparate ecosystems remains elusive. Challenges persist around asset portability and avatar interoperability across different virtual platforms. A custom-built avatar remains confined to a single walled metaverse garden like Meta Horizon or Microsoft Mesh. Purchasing a virtual Gucci bag in one world doesn't automatically transfer digitally to other environments. This fragmentation severely limits the scope and potential of the metaverse. Users wish to move fluidly between experiences, carrying their digital possessions and personas with them. Creators want to build once and deploy everywhere, not redo work for each platform. For the metaverse to mirror the connected nature of the physical world, technical infrastructure enabling this cross-platform continuity is critical. While metaverse pioneers are acknowledging this necessity, competitive pressures and commercial interests of tech giants currently take precedence over open collaboration.

The Serious Business of the Metaverse

While consumer applications have driven much of the initial enthusiasm for metaverse technologies, substantial enterprise use cases are emerging across domains like training, digital twins, and remote collaboration. These practical business applications have the potential to push adoption further into the mainstream. Immersive training simulations are already being deployed by companies like Walmart, BMW, and Lufthansa to develop employee skills and knowledge in low-risk virtual environments. Industries from aviation to medicine are utilizing digital twins of complex systems to enable virtual testing and optimization. For remote work, Microsoft is integrating metaverse capabilities directly into Teams, which has over 270 million users. This allows colleagues to collaborate via lifelike avatars and spatial layouts in virtual meeting environments. While startups are innovating, Microsoft's massive reach gives it potential to make VR meetings a workplace norm. As these use cases demonstrate concrete ROI in areas from employee productivity and safety to time and cost savings, enterprise adoption can help further validate and destigmatize metaverse technologies.

ONES TO WATCH

Andrew "Boz" Bosworth, CFO and head of Meta's Reality Labs, for being Mark Zuckerberg's right-hand man and overseeing more than 20,400 people in realizing Meta's vision for the metaverse.

Tamir Berliner and **Tomer Kahan,** co-founders of Sightful Spacetop, for innovation in spatial computing interfaces.

Tara Boroushaki, Laura Dodds, Aline Eid, and **Maisy Lam,** researchers at MIT, for contributions to augmented reality with non-line-of-sight perception.

Dr. Tim Bunnell, director at the Nemours Center for Pediatric Auditory and Speech Sciences, for work on AI-generated video clips that mimic accents and speech patterns.

Professor Garuda Fujii, researcher at Shinshu University's Institute of Engineering and ELab2, for innovative approaches to designing source-shifter structures.

Grimes, musician and artist, for pioneering new business models in AI-generated voice synthesis.

Im Doo Jung, a professor in the Department of Mechanical Engineering at UNIST, for work on smart contact lenses for AR-based navigation.

Henry Liu, professor of civil engineering and director of Mcity and the Center for Connected and Automated Transportation at the University of Michigan, for advancements in simulated driving environments.

Akash Nigam, CEO of Genies, for development of decentralized avatar systems in the metaverse.

Dr. Seung-Kwon Seol, researcher at the Smart 3D Printing Research Team at Korea Electrotechnology Research Institute, for work on smart contact lenses for AR-based navigation.

Chat Steelberg, CEO of Veritone, for advancements in synthetic Voice as a Service (VaaS) solutions.

Dr. Yu Xinge, associate professor in the Department of Biomedical Engineering at City University of Hong Kong, for co-leading a study on wireless olfactory feedback systems in VR.

Dr. Yon Visell, associate professor of biological engineering at University of California, Santa Barbara, for work on haptic holography.

Joshua Xu, CEO and co-founder of HeyGen, for innovations in translation services.

Dr. Mikael Benson, researcher at the Department of Clinical Science, Intervention, and Technology at Karolinska Institutet, for research on digital twins for treatment of inflammatory diseases.

Pouya Hamadanian, electrical engineering and computer science graduate student and lead author at MIT, for work on Ekho, which synchronizes audio and visual streams transmitting to two devices.

Elizabeth Haas, an adjunct professor at NYU School of Professional Studies, founding director at NYU SPS Emerging Technologies Collaborative, and partner at New York Consulting Partners, for writing about cities and technologies.

Dr. Sarah E. MacPherson, head of psychology and professor at the School of Philosophy, Psychology, and Language Sciences, University of Edinburgh, for her work on cybersickness in immersive digital reality.

Michael Barnett-Cowan, professor at the Department of Kinesiology and Health Sciences, University of Waterloo, for his work on motion sickness in VR games.

Jose Fuertes, founder and CEO of OWO, for developing haptic vests for virtual gaming.

Jake Rubin, founder, chairman, and CEO at HaptX, for working to bring virtual worlds to life through realistic touch.

Jensen Huang, CEO and president of Nvidia, for envisioning the Omniverse platform and developer ecosystem to build the industrial metaverse and a clear path to metaverse revenue.

Soo-yeon Choi, CEO of Naver, for instrumental work in developing the digital twin cities project between South Korea and Saudi Arabia, which will revolutionize real-time decision-making, prediction, and optimization of urban infrastructure.

Yacine Achiakh, CEO and founder of Wisear, for pioneering the development of the first earphones with a neural interface, enabling hands-free, voice-free control of XR devices.

IMPORTANT TERMS

Augmented reality (AR)
A technology that overlays digital information, images, and objects onto the real-world environment. Users see virtual elements mixed into their actual surroundings through a device screen or AR glasses/headset.

Avatar
A digital representation of a user, often in the form of a 3D model or illustration. Avatars serve as a user's persona in online/virtual environments.

Cybersickness
Nausea or motion sickness experienced by some VR users due to proprioception disorientation. It arises from the mismatch between perceived and actual spatial positions in VR, with research suggesting that factors like vertical orientation perception and inclusion of music can influence its severity.

Data portability
The ability for users to transfer their digital identities, including avatars, and associated data between platforms and services.

Decentralization
A core principle shared by the metaverse and blockchain technology, emphasizing an open network of interconnected virtual worlds, as opposed to closed, proprietary platforms.

Deepfakes
Manipulated video/audio that uses AI to realistically substitute someone's likeness and voice in existing content without their consent, raising ethical concerns.

Digital twins
Virtual replications of physical systems used for simulation and optimization.

Experiential artifacts
Lingering sensory and cognitive effects in VR users, blurring the lines between virtual and real-world experiences. These artifacts result from the dissonance between virtual and physical realities, leading to feelings of disembodiment or altered physical world perceptions.

Extended reality (XR)
An umbrella term that encompasses virtual reality, augmented reality, and mixed reality. XR provides immersive digital experiences that blend the physical and virtual worlds across a spectrum of realities. It enhances interactions with the environment and digital elements.

Haptics
Technology related to tactile sensations and feedback. Can include vibration, motion, pressure, and temperature changes.

Holography
A technique for creating three-dimensional projections; it's becoming key in populating the metaverse with realistic avatars and environments, and merging with technologies like deepfake for various applications.

Human-machine interfaces
The components and methods through which humans interact with and control machines, like keyboards, mice, touchscreens, and voice commands.

Hyperrealistic avatars
Highly detailed avatars that closely mimic a person's real facial features, expressions, and movements through advanced 3D modeling and scanning.

Interoperability
Blockchain's capability allowing assets and information to seamlessly transfer between different worlds and platforms within the metaverse.

Mixed reality (MR)
A hybrid form of reality that merges the real and virtual worlds to produce new environments and visualizations where physical and digital objects coexist and interact in real time.

Neural interfaces
Technologies that connect directly to the user's neural activity, like brain waves or facial muscle signals, to enable hands-free and silent control.

Non-fungible tokens (NFTs)
Unique digital assets representing ownership of virtual items like land and avatars in the metaverse, made credible and secure through blockchain technology.

Olfactory feedback
Technology that generates smells and aromas digitally, allowing smells to be simulated in a virtual environment.

Panopticon
A system of control where individuals are aware they might be watched at any time, leading to self-regulation of behavior. In the context of smart glasses, it refers to the heightened sense of being observed and changing behavior because of it.

IMPORTANT TERMS

Passthrough
A feature in some headsets that uses outward-facing cameras to display the physical environment to the user while wearing the headset. Provides awareness of surroundings.

Play-to-earn games
Virtual environments in the metaverse where players can earn real-world value through gameplay, with blockchain technology enabling the collection, breeding, and trading of digital assets as NFTs.

Situated virtual reality (situated VR)
A concept proposed to align the physical and virtual worlds, minimizing experiential artifacts. It focuses on syncing physical actions with virtual feedback to create a congruent reality, including mirroring body language and emotional expressions in virtual and real worlds.

Synthetic personalities
Fully artificial digital influencers and identities generated through AI training, not tied to any specific human individual.

Synthetic speech
AI-generated simulated speech that clones a person's vocal characteristics to create natural sounding vocalizations. Enables voice banking, which benefits people who may lose their ability to speak later in life.

Virtual reality (VR)
An artificial digital environment that is fully immersive and isolates users from the physical world. Users typically wear a headset with stereoscopic displays and head tracking to look around the virtual world.

METAVERSE FORM FACTOR

METAVERSE FORM FACTOR

Headsets

While early virtual reality headsets offered consumers an escapist diversion, the technology is maturing, and developers are now targeting more pragmatic industries and experiences. The Meta Quest 3, for instance, brings a 30% improvement in screen resolution, faster processing speed, and a sleeker design. Most notably, outward-facing passthrough cameras allow wearers to view both physical and virtual surroundings. This "mixed reality" mitigates the isolating feel of previous models. Apple's forthcoming Vision Pro is also set to incorporate similar passthrough technology, highlighting an industry-wide acknowledgment of the need for more interactive and less isolating VR experiences. The Vision Pro will launch with an expansive app library spanning entertainment to productivity. Major streaming services like Disney+, ESPN, and Amazon Prime Video will be available alongside work apps like Microsoft 365, Slack and Zoom.

Meta's substantial price hike compared to its predecessor indicates a strategic pivot from targeting general consumers to focusing on enterprise applications. This repositioning places the headset in direct competition with established enterprise-focused devices like Microsoft's HoloLens 2 and Magic Leap 2. Sony's version, the SonyXR Headset is primarily tailored for industrial applications, aiming to integrate various production stages, such as design and prototyping, into the metaverse. By allowing users to construct 3D design models, the headset helps spot and fix problems while plans are still digital, saving money previously spent on faulty physical prototypes.

Rather than pure escapism, developers seem concentrated on increasing VR/AR functionality across specialized fields moving forward. Allowing real environment interaction reflects acknowledgment of earlier issues in consumer adoption, while enterprise and sensory enhancement applications point to an evolving market for the technology.

Smart Glasses

Developments in smart glasses aim to make spatial computing technology subtle yet powerful in daily life. In a landmark September 2023 announcement, Meta collaborated with EssilorLuxottica to unveil Ray-Ban glasses with built-in AI capabilities. Resembling traditional Ray-Bans in design, these glasses integrate multimodal sensors to interpret the user's gaze and voice commands. Whether the wearer is curious about a building or needing a sign translated, Meta's assistant can provide answers without hand gestures. Snap plans similar AI integration for contextual recommendations and on-lens edits. Apple likewise has plans to introduce augmented reality glasses, though details are still forthcoming. Meanwhile, Microsoft recently patented swappable batteries for extended power, potentially enabling comfortable all-day wear by reducing weight. Offloading processing functions to connected accessories like backpacks presents another option for portable use.

Though slimmer smart glasses would blend into social settings better than bulky virtual reality headsets, battery limitations pose ongoing challenges to unlocking the full capabilities of the sleeker wearable technology.

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In early 2024, BMW introduced AR technology in their cars with the help of XrealAir 2 AR glasses. These glasses show navigation, entertainment, and electric car charging information directly to the driver. The introduction of smart glasses in vehicles and into other parts of our daily life is more than just a technological advance; it's a societal shift. Mobile phones revolutionized the way we interact with the world—pausing to record moments or look up information. Smart glasses promise the same but with an added layer of immersion: You can live stream your experiences while remaining fully present. However, this comes with questions about the implications for interpersonal interactions. Will behavior change in a world where people know they could be continually recorded or analyzed by AI? In essence, smart glasses aren't merely a new gadget; they represent a significant leap toward pervasive computing and could fundamentally alter our relationship with technology and each other.
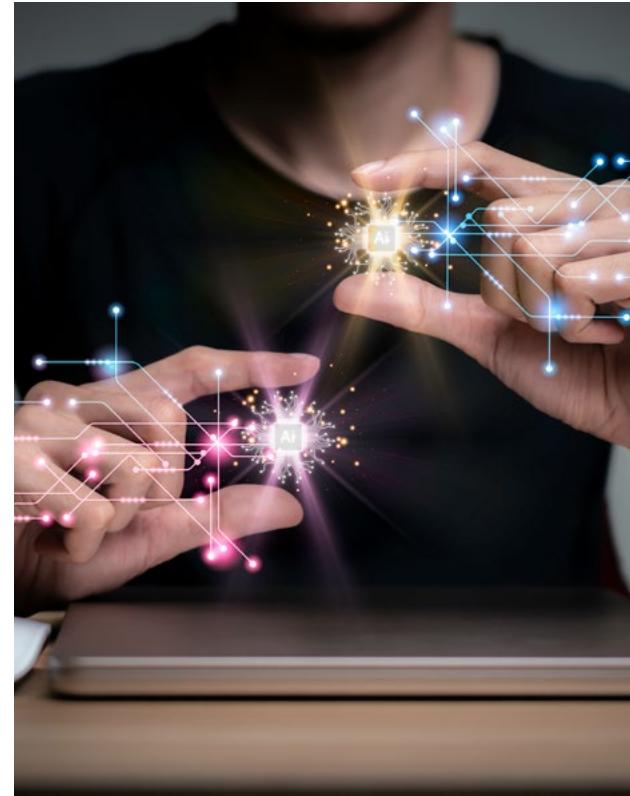
Haptic Wearables

Virtual worlds to date have focused primarily on visual and auditory immersion, but replicating tactile sensations presents the next frontier for technologies like metaverse platforms to conquer. The ability to not just see a virtual object but reach out and feel textures, weights, and movements would provide unprecedented realism. To enable this, developers are experimenting with haptic wearables—gloves, vests, or suits equipped with actuators to simulate different sensations through vibration, electrical stimulation, or even tiny inflatable balloons. Simple vibrational alerts via eccentric rotating mass motors are already featured in smartphones and controllers, priming adaptation for games and 3D virtual environments. Companies like HaptX are leveraging more advanced pneumatic glove actuators to replicate lifelike textures and shapes. Spanish startup OWO recently unveiled a haptic vest using electrical signals to induce sensations including bullet impacts or stabbings for gaming and live entertainment applications. As these devices advance alongside motion

tracking systems like Sony's full body suit loaded with sensors, the building blocks are falling into place for the creation of deeply immersive and tactile responsive spaces within virtual worlds. The end goal is ambitious yet attainable: to produce a metaverse experience that fully engages users across visual, auditory and, critically, tactile domains to enable suspension of disbelief and flow state immersion.

Voice, Gesture, and Neural Interfaces

Human-computer interaction continues progressing beyond phones and screens, leveraging modalities like voice and gesture. Virtual assistants have normalized conversational AI, powered by robust speech recognition models. Startups are unveiling experimental devices prioritizing intuitive interactions, like Humane's screenless wearable pin, which understands natural language requests. Meta's Ray-Ban Stories glasses allow hands-free voice control, while their VR headsets track hand motions to manipulate virtual objects. Apple's Vision Pro will combine subtle finger gesture rec-

Just as touchscreens became widespread in the last decade, voice and gesture control are poised to be the next major methods for interacting with computers.

METAVERSE FORM FACTOR

ognition with eye tracking, enabling users to simply look at and point to items they want to select in an augmented environment. Wisear, a French startup, is pushing the boundaries even further with experimental smart earbuds that detect facial muscle movements and bioelectrical brain signals. By interpreting these neural signals, Wisear envisions completely silent, hands-free control of devices through minute gestures like tightening the jaw. Just as touchscreens have become ubiquitous over the past decade, emerging modalities like voice, eye tracking, and brain-computer interfaces could fundamentally transform how we engage with technology in the next 10 years.

Senses in the Metaverse

Recent advancements in human-machine interfaces are ushering in a new era of multisensory experiences in VR and AR. On the haptic front, researchers at the University of California, Santa Barbara have focused ultrasound waves to induce tactile sensations from afar. This noncontact "haptic holography" allows users to perceive and manipulate virtual objects. To deepen sensory immersion without physical temperature changes, University of Tsukuba researchers simulate persistent cold sensations through gentle air blasts. This exploits the body's sensitivity to rapid cooling for virtual weather experiences. In odor transmission, Dr. Yu Xinge's team at Beihang University developed wireless olfactory feedback systems with miniaturized odor generators. Integrating face-masks and skin patches, these can simulate environmental scents ranging from flowers to smoke. Startup OVR makes headsets that diffuse cartridge fragrances for personalized aroma experiences. Advances also continue in spatialized audio for lifelike acoustics. Professor Garuda Fujii of Shinshu University engineered structures that make sounds that seem to originate from different locations. By tricking the ears' spatial perception, more convincing augmented soundscapes become achievable. As these technologies mature, they pave the way for unified multisensory environments—where users not only see and hear but feel, smell, and taste simulated worlds for unprecedented presence.

Movement in the Metaverse

Disney has developed a new flooring technology called HoloTile that allows users to walk freely in any direction without actually moving from their fixed location. Described as the "world's first multi-person, omnidirectional, modular, expandable treadmill floor," HoloTile uses advanced sensors and motors to detect a person's movement and seamlessly shift modular floor sections to keep them centered in place. Multiple people can use the floor simultaneously without the risk of colliding. In a demonstration video, inventor and imagineer Larry Smoot walks through a virtual environment using a headset while the HoloTile floor adjusts dynamically beneath him. This technology opens up new possibilities for virtual reality and augmented reality, as well as applications like interactive theater where actors could explore a scene without constraints. Disney isn't alone in its effort to enable more natural movement in the metaverse. Other companies are exploring similar technologies for natural movement in virtual spaces. Virtuix has developed a VR treadmill for indi-

vidual users, featuring a concave design and special shoe covers for a realistic walking sensation. Additionally, Freedom Technologies is working on specialized shoes with AI-enabled motorized treadmills in the soles, allowing for unlimited virtual movement in a confined physical space. These innovations represent different approaches to enhancing virtual mobility, and it's still unclear which will dominate the market. The choice may depend on specific use cases and user preferences in VR and AR experiences.

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A House Divided

The Komanduri family finds themselves in a dilemma: a "house divided" not by sports teams or smartphone preferences, but by their choice of AR/VR ecosystems. The eldest child, Aditya, is an avid fan of Apple's AR/VR ecosystem, boasting the latest Apple AR headset and an array of digital accessories. Meanwhile, the younger sibling, Priya, is deeply immersed in the Meta universe, equipped with the newest Meta Quest and a collection of Meta-exclusive digital games and experiences. This division has led to more than just friendly sibling rivalry; it's become a logistical and financial headache for the parents. Planning family activities in the virtual realm is nearly impossible, as each child is locked into their respective ecosystems, unable to interact or join the same digital spaces.

The financial strain is palpable. The family has to subscribe to two different "family plans" to accommodate both ecosystems. What's more, the digital goods and games purchased for Aditya cannot be passed down to Priya, negating the possibility of "hand-me-downs" that would have been a cost-saving grace. This means doubling up on purchases for similar experiences or content, a redundancy that's both frustrating and expensive.

Birthday and holiday gifts have also become a challenge. A game or digital accessory that delights Aditya is incompatible with Priya's Meta setup, and vice versa. This has led to careful, sometimes stressful planning to ensure equity and satisfaction for both children, further adding to the family's expenses.

DIGITAL IDENTITY

DIGITAL IDENTITY

Avatars

Avatars have matured beyond static profile images into multifaceted digital representations in virtual spaces. Initially serving as basic profile pictures, modern avatars manifest as interactive 3D entities capable of conversation, environmental navigation, and even simulated physical mannerisms. As online activities shift from websites and apps toward immersive extended reality (XR) metaverse experiences, avatars are becoming our primary digital personas—used for social connections, commerce, and professional meetings. Microsoft enables Teams users to utilize 3D avatars for calls, animated by voice cues to function sans webcams. And a 2023 podcast hosted in the metaverse demonstrated major upgrades in avatar realism, utilizing lifelike models of Mark Zuckerberg and Lex Fridman. This noticeable leap from previous cartoonish renditions drew significant public and investor interest by making broader metaverse goals appear more attainable. Companies like Genies are further expanding the scope and utility of avatars by working on open, decentralized systems that let users create not only their virtual selves but also the worlds they inhabit. This development opens up new opportunities for user engagement and potentially impacts how businesses operate in virtual environments. As avatars grow increasingly sophisticated in mimicking human appearance, motion, and interaction modalities, they reinforce their status as our digital surrogates across the internet's burgeoning virtual frontiers.

Avatar Portability

Avatar portability in the metaverse, as facilitated by companies like Ready Player Me, intersects with larger discussions about data portability and ownership. Ready Player Me and its partner, Koji, offer users the ability to create a unified digital identity that can migrate across over 200 games and virtual experiences. While this offers convenience and customization, it raises questions about who truly owns these digital identities. Your avatar, after all, is a form of data. Whether it's a visual approximation of you based on uploaded photos or a purely imaginative creation, the avatar is shaped by your preferences and actions. As such, the issue of avatar portability is inextricably linked to debates about data ownership. When an avatar can cross platforms, there's a tacit understanding that its underlying data should also be portable. But who owns that data, especially as avatars become increasingly sophisticated and personalized, is a point of contention. The issue is even more critical when considering that some metaverse companies aim to become comprehensive platforms for a wide range of activities, from reading news to socializing to shopping. In such a scenario, the platform that hosts your avatar could have significant power and control over a large swath of your personal data. So, while Ready Player Me's tools for avatar creation and portability offer users the ability to maintain a consistent digital identity across the metaverse, they also open up broader discussions about data ownership and portability in virtual spaces.

Hyperrealistic Avatars

Hyperrealistic avatars leverage 3D graphics and AI to produce nearly identical digital clones of individuals—capturing intricate facial details, expressions, and motions. Two methods exist for generating these sophisticated models. Companies like Doob utilize full body scans in studios, comprehensively recording the user's physical form. Alternatively, apps like Avatar SDK and itSeez3D enable DIY facial scanning directly through smartphone cameras. By taking a 360 degree image of their face and shoulders, users can craft impressively realistic avatar likenesses. Integrating natural language processing and vocal mimicry, these avatars graduate beyond appearances to also simulate voices, producing holistic digital surrogates. One pioneering example was during the recent taping of Lex Fridman's podcast with Mark Zuckerberg in the metaverse. Utilizing Meta's advanced "codec avatars," their uncannily realistic digital doubles exhibited nuanced mannerisms and conversations.

As solutions like HeyGen's AI-powered Avatar Clones push fidelity even further, lines blur between actual and simulated realities. While constructive applications await in gaming, en-

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terprise metaverses, and beyond, deep ethical questions emerge around authentic digital identity and behavior. Ultimately though, as avatar technology continues maturing to deliver hyperrealism, it will profoundly transform how we represent ourselves and interact in online spaces.

Fragmentation of Virtual Identity

Without a standardized, universal avatar system, users on various digital platforms create multiple online personas, each representing distinct facets of the self or even entirely fabricated alter-egos. This emerging paradigm signals a seismic shift in conceptualizations of identity in the digital era. We now face not just divergence between our physical and virtual selves but the fragmentation of singular legible personalities across ever-proliferating online spheres. A glimpse of this reality already manifests professionally. An individual may use one avatar, precisely modeled after their real-world appearance, for Microsoft Teams meetings. But the same person could adopt a fanciful, anonymized persona for recreational gaming universes.

For marketers reliant on data analytics, such compartmentalized self-representation poses challenges. When consumers have multiple discrete avatars, extracting useful signals becomes far more complex. Which identity should companies target for personalized advertising? How to accurately track preferences when individuals act differently across contexts? Ultimately, the fracturing of singular legible identities into specialized avatars requires businesses to fundamentally rethink behavioral analysis and personalization methodologies. As personas multiply across the metaverse, understanding users grows increasingly nuanced.

Leasing identity

AI is enabling digital replications of celebrities without their active participation or consent—an ethically murky development as likeness rights remain undefined. The 2023 Hollywood writers' strike spotlit concerns around studios exploiting synthetic acting indefinitely sans compensation. Meta recently launched celebrity chatbots like virtual Paris Hilton and Snoop Dogg alter egos,

playing circumscribed roles on WhatsApp, Messenger, and Instagram. And deepfake technology already allows for CGI actor substitutions in film or ads without a physically present cast. When Bruce Willis retired for health reasons, his likeness still appeared in a Russian commercial via a deepfake generated by an AI company. To address this issue, new contract language around "simulation rights" is beginning to appear, allowing for the legal use of an actor's synthetic likeness in future productions. The music industry is also tapping into this trend; artists can now create songs using an AI-generated voiceprint of musician Grimes, splitting the royalties with her if she approves the collaboration. These early examples highlight the emerging potential to monetize synthetic celebrity beyond entertainment—anyone could perhaps license out digital persona rights for conversational AI, branding deals, or experiential metaverse content. But thorny questions around likeness consent and fair compensation remain open, especially as technology blurs lines between virtual replication and individual autonomy.

AI is enabling the creation of digital replicas of individuals' appearances and voices, opening avenues for monetizing identities.

DIGITAL IDENTITY

Synthetic Speech

Synthetic speech leverages AI to digitally mimic human voices, enabling myriad applications from accessibility tools to creative media. With enough training data, models can precisely replicate the unique vocal signature of any individual. Startups like HeyGen offer translation services that render personal video recordings into foreign languages, while retaining the original speaker's voice. Meta is also developing real-time speech translation to break language barriers using natural voice cloning. And new models need as few as 50 sentences to build vocal profiles, making synthesis more efficient and accessible. Samsung demoed a feature for its Bixby assistant to verbally respond to calls in a user's synthesized voice if they are unable to speak. Other applications of speech synthesis include "voice banking," where people at risk of losing their ability to speak due to disease can record samples that AI uses to synthesize their voice. This allows them to preserve their unique vocal identity for text-to-speech systems if they do need it later in life. Previously expensive and time-consuming, voice banking has become more efficient and affordable through AI, with some companies only needing 50 sentences to create a digital voice.

Synthetic Personalities

Beyond mimicking existing personas, large language models (LLMs) can invent completely synthetic yet persuasive media identities from scratch. After ingesting enough human data patterns, AI can reliably simulate varied personality dimensions within text or embodied conversational agents. Researchers deliberately shape these traits to craft AI virtual influencers—novel social media personas like Lil Miquela, Noonoouri, and Imma, each boasting 400,000+ Instagram followers. Instead of cloning celebrities, their personalities and backstories emerge fully formed from algorithms to fulfill commercial roles. Brands like Coinbase, Maje, and Tiffany & Co. have partnered with these AI-driven virtual influencers for endorsements and promotions. The control and presumed brand safety offered by synthetic influencers makes them an attractive alternative or supplement to human influencers. In 2023, the Federal Trade Commission indicated that virtual influencers must still disclose brand sponsorships like their human counterparts. As immersive spaces like the metaverse develop, AI-driven synthetic personas could enable personalized interactive brand experiences exceeding static posts. The technology remains nascent—but rapid improvements in AI personality exhibition point toward virtual influencers, celebrities, and beyond materializing as bona fide social presences, engineered from data to serve economic aims over authentic self-expression.

Synthetic personalities are entirely artificial digital influencers and identities created by AI, not linked to any real human.

APPLICATIONS

APPLICATIONS

Virtual Training for Real World Jobs

Virtual reality enables immersive job training simulations across industries from retail to medicine, with measurable improvements in information retention and role comprehension. Companies like Walmart have incorporated VR into training as early as 2017, reporting 5%-10% testing gains versus classical training. Simulations run the gamut from customer scenarios like Black Friday to operational skills like spill cleanups. Maryland nonprofit Vehicles for Change likewise has trainees first pick up VR goggles instead of physical tools to observe demonstrations and practice procedures before touching actual cars. Aviation leaders including Lufthansa also apply extended reality across domains from product design to flight crew certification. The technology provides a low-risk yet realistic environment to build muscle memory and mastery of complex tasks, from retail soft skills to technical maintenance procedures. Hands-on learning through lifelike simulation before real-world performance allows workers to avoid consequences as they develop confidence. With customizable training exportable across geography, VR promises scalable and measurable skill-building superior to static manuals or lectures. Trainees engage more senses in contextualized scenarios, enabling organizations to elevate talent development.

Industrial True-to-Reality Simulations and Digital Twins

True-to-reality digital twins are revolutionizing industries from autonomous vehicles to smart cities by enabling virtual testing and optimization of complex real-world systems. The University of Michigan developed a statistically accurate simulated roundabout to rigorously refine self-driving algorithms without physical risk. BMW likewise models exact factory conditions in Nvidia's Omniverse platform years before producing a new car to optimize layouts and processes. On a macroscale, digital urban twins facilitate data-driven planning and governance. South Korean company Naver partnered with Saudi Arabia to craft cloud-based digital clones of Riyadh and other municipalities. These foundations centralize infrastructure data to assist long-term development across domains from transportation to emergency response. Numerous metropoles worldwide have embarked on urban twin projects—from Shanghai to Singapore to Chattanooga. The city of Chattanooga itself collaborates with research institutions on specialized twins examining factors like energy-efficient mobility infrastructure and pedestrian-vehicle intersection patterns to inform planning. As cloud computing power scales, digital urban replicas grow increasingly high-fidelity to run simulations and extract insights unfeasible in the real world. The technology enables observers to holistically visualize, quantify, and optimize the intricate orchestration of modern cities.

Human Digital Twins

Research institutions are pioneering medical digital twins—detailed physiological simulations of individual patients for personalized care and quantitative analysis. These complex computational models incorporate genetic, molecular, and environmental factors to replicate disease mechanisms with high precision. In conditions like rheumatoid arthritis, Crohn's, and ulcerative colitis, health care teams can leverage twins to run clinical scenarios—predicting outcomes of adjusted drug regimens to tailor optimal treatments. The simulations also enable deeper study of biological drivers and responses in silico. Medical twins diverge from simplistic avatars by encapsulating dynamic physical detail beyond just identities. Researchers ultimately envision diagnostic, prognostic, and even two-way communication functions as integration with sensor data and AI intensifies.

However, as computing power expands, digital twins may mature beyond niche medical uses alone. More advanced systems could maintain dynamic multifaceted models of individuals—incorporating both medical and psychological factors to mimic personality, knowledge, and behaviors. Researchers envision such sophistication may eventually enable twins to serve as persistent, autonomous virtual agents for their human counterparts. These highly faithful digital doppelgängers could seamlessly interact with people and other twins in virtual spaces or the metaverse. They could collabo-

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rate in ways impossible for remote humans, collectively analyzing problems through continuous data sharing exceeding biological cognition limits.

Connected Well-being and VR Assisted Therapy

VR is increasingly being recognized as a powerful tool in the field of psychological therapy and mental health treatment. VR's origins in mental health date back to 1997, when it was first invested in for treating PTSD in military populations. One major application is virtual reality exposure therapy (VRET): leveraging simulated environments to gradually confront patients with anxiety disorders. VRET allows for a controlled and personalized intervention where patients can confront and become accustomed to the sources of their anxieties in a virtual setting. The treatment has proven to be as effective as traditional in-person exposure therapy for conditions like specific phobia and agoraphobia with panic disorder. Interventions for post-traumatic stress disorder likewise show VR matching traditional psychotherapy techniques

for symptom relief. Beyond exposure, the immersive medium also aids in developing coping mechanisms. Recent studies, such as a pilot project by Stanford Medicine researchers, have also started using VR to address hoarding disorders. Study participants rehearsed giving up possessions in a simulation of their own homes, an exercise that helped them practice organizational and decision-making skills while also desensitizing them to the emotional distress associated with discarding items. As software and analytical dashboards improve, VR appears poised to mainstream into mental health—blending digital solutions with clinical wisdom for more agile, quantified, and personalized interventions.

Medical Metaverse

The metaverse enables transformative innovations in medical education and care delivery via immersive simulation. Medical students can now perform virtual neurosurgery to improve their technical skills before operating on actual patients. The University of Texas uses a VR "patient safety room"

where students identify hazards and discuss observations with professors, allowing for more effective training than traditional methods. However, while AI tutors in VR can provide tailored feedback like a human instructor, human oversight is still needed. A McGill University study found VR trainees with additional human instruction caused less tissue damage and were more precise than those trained by AI tutoring alone. Platforms like Fundamental Surgery additionally provide sophisticated haptic feedback for practicing complex manual tasks from palpating tissue to maneuvering instruments. Its patented HapticVR technology accurately simulates the tactile sensations experienced during surgery, from bone textures to muscle and soft tissue interactions. FundamentalVR also recently launched its Fundamental Core SDK, a toolkit empowering developers to create diverse medical training scenarios, including multiuser VR experiences.

Beyond training, AR and VR are being used for patient care and surgical planning. In Cambridge, England, medical students use

AR and VR are already utilized in surgical planning and training, enabling surgeons and patients to preview expected outcomes. At least one hospital has used AR headsets during complex surgeries to overlay patient data in real-time.

SCENARIOS

Exploring Mars with Man's Best Friend

After strapping on the haptic suit and headset, I'm immersed in a stark reddish-orange alien landscape that can only be Mars. As I "step" forward, I feel the crunch of strange soil beneath metal feet that are not my own. This body is an extension of mine—its sensors connected directly to my nervous system via a neural link system. When I lift my foot, the robot lifts its tread. When I reach out my hand, its claw extends. My consciousness inhabits this machine shell millions of miles away, and I'm seeing Mars directly through my avatar's camera eyes. Every sensation is mapped from its tactile sensors to my own synapses, blurred with just enough latency to make the illusion complete. This robot is me, and through it I have stepped onto the surface of another world for the first time.

But what truly anchors me in this extraordinary experience is Moe, my dog. She's not just lying next to me in the physical world; she's also here with me on Mars, in a way. When I adopted Moe, she came with something special: a digital twin. This isn't a virtual pet; it's a precise digital clone, created from detailed scans and biometrics, designed to mimic every physical detail of Moe. Initially, these digital twins were meant for health monitoring, a technological advancement in pet care. But soon, people realized their comforting potential in strange, digital realms. Here on Mars, as I navigate through vast, sweeping vistas, Moe's digital twin is right beside my avatar. As I explore, I occasionally reach down to pet the real Moe, feeling her warm fur, and then I see her digital doppelgänger reacting similarly beside my avatar. It's a bizarre yet heartwarming experience to have both versions of my best friend with me as I explore this alien world.

As night falls on Olympus Mons, I gaze out transfixed with my loyal dog clone by my side at a view no earthling has witnessed firsthand. Her presence, just like the real Moe, comforts me—two versions of man's best friend, one analog, one digital, both equally enthralled by this alien world we get to explore together.

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mixed reality headsets to train on "hologram patients," while Swiss company Arbrea Labs employs AR and 3D simulation to allow both surgeons and patients to preview expected outcomes of plastic surgeries, from nose jobs to breast augmentations. Surgeons at institutions like Houston's MD Anderson Cancer Center utilize AR headsets to overlay patient data seamlessly during complex procedures—establishing a new paradigm of in-situ surgical guidance.

Education in the Metaverse

Research has indicated the efficacy of VR in enriching learning experiences. Recent findings suggest VR contributes to improved understanding, heightened attention spans, and inclusive access to digitized global curriculum exceeding geographical constraints. Real-world implementations demonstrate scalability too. Japan's N and S high schools immerse over 6,000 students in collaborative virtual classes using Meta Quest headsets. Morehouse College's VR chemistry labs yield higher average test scores than conventional modalities. Beyond supplemental content,

interactive platforms like RoybiVerse and Nanome reconstruct traditional models for more intuitive handling. Learners can manipulate molecular structures with their hands or traverse inside dinosaur anatomy. By blending immersion with interactivity, VR edtech unlocks multisensory comprehension of abstract or ephemeral concepts at individual scale.

Synthetic Media in Hollywood

The rise of synthetic media in Hollywood, accelerated by advancements in AI, is bringing both opportunity and ethical dilemmas to the industry. The 2023 Screen Actors Guild strike revolved around usage of talent likenesses without clear restrictions. Ironically, during the strikes, Meta and a company called Realeyes capitalized on the abundance of out-of-work actors by hiring them for an "emotion study" aimed at making AI-generated avatars appear more human. These actors signed away extensive rights "in perpetuity," allowing their facial expressions and other characteristics to be used by Realeyes, Meta, and third parties almost

without restriction. This move clearly brings into focus the ongoing debate about publicity rights, the legal concept that grants individuals the right to control the commercial use of their name and likeness.

At the same time, examples of synthetic media featuring well-known actors are growing. For instance, James Earl Jones authorized the use of his iconic Darth Vader voice so AI could generate it for future "Star Wars" films. Companies like Metaphysic AI are employing de-aging technology, allowing stars like Harrison Ford, Tom Hanks, and Robin Wright to appear as younger versions of themselves on screen. In 2022, after a 40-year hiatus, ABBA made a comeback with fresh music, accompanied by their de-aged 3D avatars, known as ABBAtars. In 2023, Kiss bid farewell to the stage at their final performance in Madison Square Garden—only to reemerge minutes later as digital avatar versions of themselves, suggesting virtual immortality for these personas powered. Platforms like Weverse give K-pop artists opportunities to directly engage followers through virtual

meetups while monetizing exclusive digital content. As immersive media expands, existing regulations around reasonable compensation, consent, and protections demand modernization to address ethical dimensions related to identity replication via emerging technologies.

Forensic AR / VR

AR and VR show great potential in advancing forensics. Sophisticated AR/VR crime scene simulations facilitate analysis even when the physical location remains inaccessible after the fact. Some systems use machine learning and medical imaging to enhance AR-assisted autopsies, leading to more accurate victim identification and determinations of cause of death. A major advantage of AR/VR is the ability to visualize complex forensic data in new ways. AR overlays digital information directly onto physical crime scenes, allowing for dynamic interaction like real-time tagging of evidence and voice-recorded annotations. In the legal system, AR and VR are modernizing evidence presentation in courtrooms through 3D modeling and mapping to provide an
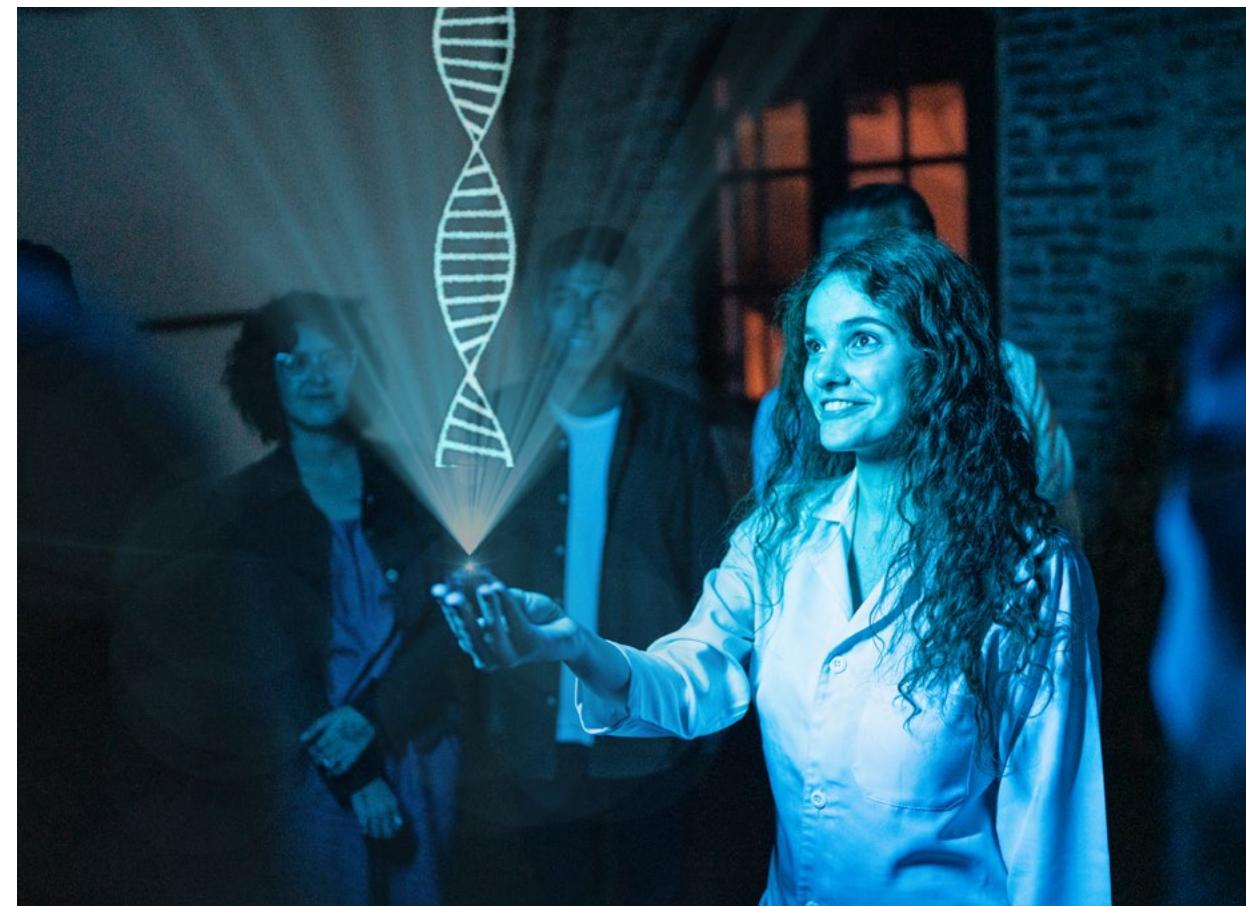
APPLICATIONS

immersive crime scene experience for judges and jurors. This boosts understanding of complex evidence sequences. These technologies also facilitate remote testimony for improved accessibility. On the training side, companies like CBF Forensics use realistic VR simulations to deliver cost-effective forensic skills training for law enforcement. While still emerging, AR and VR integration in forensics promises to enhance remote capabilities, evidence presentation, and training.

Metaverse-Enhanced Science

The metaverse could significantly enhance the effectiveness and reach of science. Its interactive, three-dimensional spaces provide opportunities for unprecedented levels of collaboration and accessibility in research. For example, digital replicas of physical labs can enable scientists around the globe to get together and discuss and advance projects, bypassing geographic and logistical constraints. Experiments conducted in virtual environments have the added benefit of being precisely replicated, improving the reproduc-

ibility of research findings. Agencies like the Centers for Disease Control and Prevention are already leveraging the metaverse to train scientists in various locations, allowing them to engage in experiential learning without the real-world risks. Moreover, the metaverse allows for the creation of entirely new kinds of experimental spaces. For instance, scientists could utilize existing data and images to develop virtual models of far-off places, such as Mars, and remotely engage with these environments. However, realizing the metaverse's full promise requires surmounting adoption obstacles around equipment costs and centralized tech giant control.

Digital lab replicas could allow scientists to collaborate and perform virtual experiments mirroring real-world conditions, reducing costs and increasing accessibility to experimentation.

SCENARIOS
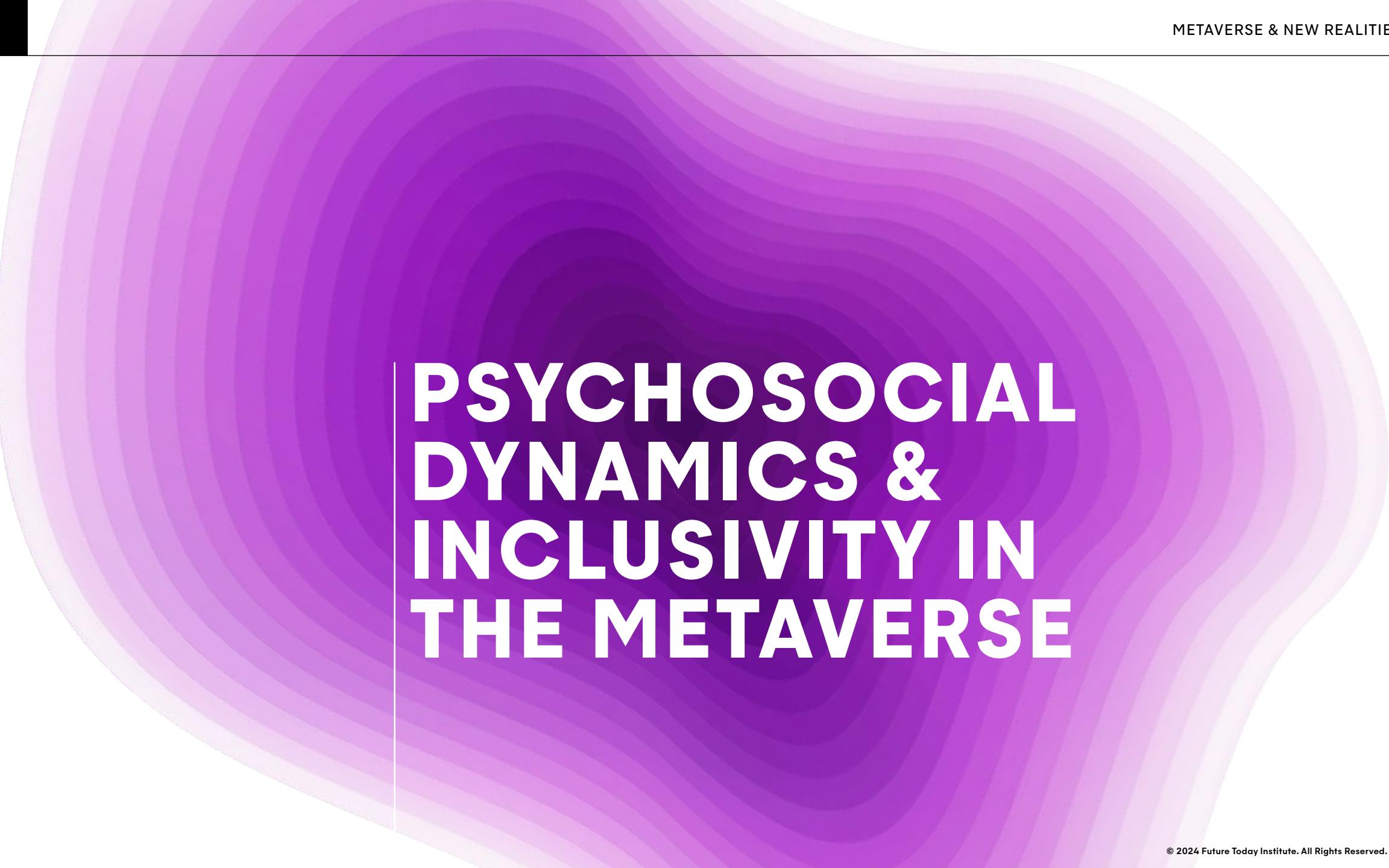
Experiential Equations

Daniel slips on a headset, eager to explore the immersive calculus simulator his teacher introduced in class. As the virtual world loads, Daniel finds himself standing on an abstract grid landscape, with colorful curves undulating in all directions. He reaches for a squiggly purple function in front of him, knowing that in this virtual world he can physically interact with the fundamental building blocks of mathematics.

"Today I want you to explore the concept of curvature," the instructor's voice emanates from the air. "Take this controller and manipulate the curve in front of you. Get an intuition for how bending changes along the arc." Daniel reaches out and takes hold of the squiggly purple function. As he moves his hands, the curve reshapes itself like virtual taffy. Daniel instantly understands the curve better than equations on paper could convey—he feels how tapered regions have lower curvature than tight curls.

"Now, let's step into a derivative's shoes," the instructor says. The world blinks, and Daniel's perspective shrinks. He has become the orange derivative denoting the curve's slope! As he glides along the ripples of the function, Daniel physically experiences each peak and valley in its slope and their full spatial relationship clicks intuitively. The immersive manipulations unlocked conceptual knowledge allowing math to finally make sense. He had felt what those cryptic formulas tried explaining: that curvature captures the rate of direction change. VR let Daniel enter into mathematics, instead of just staring formulaically. Equations had become experience.

PSYCHOSOCIAL DYNAMICS & INCLUSIVITY IN THE METAVERSE

PSYCHOSOCIAL DYNAMICS AND INCLUSIVITY IN THE METAVERSE

Situated VR

In the metaverse, the dissonance between virtual and real-world experiences often leads to "experiential artifacts," a phenomenon where VR users experience lingering sensory and cognitive effects that blur the lines between these two realities. This issue arises from the noncongruent realities that users encounter when transitioning between digital and physical spaces. Users may feel a surreal detachment from their bodies or environment, reporting feelings of disembodiment or altered perceptions of the physical world after VR sessions. These experiential artifacts are a result of the complex interplay between our sensory inputs and past interactions with the world, evolving as we are exposed to various contexts, including virtual environments. Recognizing the psychological impacts of these artifacts, which can range from mild curiosity to disorientations affecting daily life. Researchers at MIT have proposed "situated virtual reality" as a solution. This concept, currently under review for publication in IEEE, aims to align the physical and virtual worlds, minimizing experiential artifacts. Situated

VR focuses on syncing physical actions with virtual feedback, such as matching natural movement or object interactions, to create a more congruent reality. The approach also extends to social interactions, ensuring that the body language and emotional expressions in virtual environments mirror those in the real world. The goal is to establish a hybrid reality that is free from experiential artifacts, prioritizing not just technological innovation but also the psychosocial well-being of users in the metaverse.

The Panopticon

The psychological effects of being constantly filmed, particularly when interacting with individuals wearing smart glasses, can be significant and multifaceted. Smart glasses, which may be always recording or perceived as such, introduce a dynamic similar to the concept of a panopticon in social interactions. The panopticon refers to a system of control where individuals are aware that they might be watched at any time, leading to self-regulation of behavior due to the perception of constant surveillance. When interacting with someone wearing smart glasses, people may act differently when they experience a heightened sense of being observed. This phenomenon is similar to the observer effect in psychology, where individuals modify their behavior in response to their awareness of being watched. In social contexts, this can lead to increased self-consciousness, anxiety, and potentially altered social dynamics.

The introduction of "trust lights" on some smart glasses, designed to indicate when recording is taking place, attempts to mitigate this effect by providing a visual cue to others about their privacy status. On the Ray-Ban Meta smart glasses for instance, the camera will not record if the LED light is covered. However, the effectiveness of these trust lights in alleviating concerns about privacy and constant surveillance is not clear-cut. While they might offer some reassurance, the underlying tension and psychological impact of potential constant recording remain.

XR Accessibility

Accessibility XR is a growing area of focus, aiming to ensure these immersive technologies are inclusive for all users, including those with disabilities. Key areas of accessibility in XR include sensory, physical, cognitive, and universal design aspects. For example, Google's ARCore improves environmental understanding, crucial for users with visual impairments. The design of XR interfaces is evolving to cater to diverse physical abilities, incorporating features like voice commands and eye tracking. Microsoft's inclusive design approach in VR and AR, featuring voice recognition and adaptable controller settings, exemplifies this advancement. Similarly, many companies now offer voiceover support in AR experiences, aiding visually impaired users with audio descriptions. Cognitive accessibility is also a priority, particularly for users with conditions like autism, necessitating simplified interfaces and controlled sensory inputs. Meta Quest demonstrates this by providing customizable controls and head tracking options for users with limited mobility.

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Many efforts in the XR accessibility space are underpinned by the principles of universal design, aiming to create XR experiences that are inclusive and enjoyable for everyone, regardless of their abilities. Leading this charge are initiatives like the XR Association's Accessibility Working Group and the XR Access Initiative, which bring together industry, academia, and advocacy groups to research, develop, and educate about accessible XR technologies, ensuring that the immersive digital world is open and welcoming to all.

Diminished Sensory Overload

People with autism spectrum disorder (ASD) often struggle to process sensory information, finding stimuli like bright lights or loud noises particularly overwhelming. This sensory sensitivity can turn routine activities into significant challenges. Augmented reality presents a promising tool to mitigate these sensory integration issues. AR's ability to create controlled and customized environments can gently introduce sensory inputs to those with ASD, allowing them to adapt at a comfortable pace. Among the innovations in this field are "Unfear" and "Floreo," which use technology to create supportive spaces for individuals with ASD. Samsung's Unfear is an app that uses real-time selective noise filtering to reduce auditory stress. It targets specific sounds that are distressing to the user, offering a more relaxing and fear-free auditory experience. Unfear also extends its functionality to digital content, like mobile games, filtering out loud sounds to make such media more accessible for those sensitive to audio intensity. Though not an AR application per se, Unfear embodies principles that could be integrated into AR platforms. Floreo, on the other hand, directly utilizes AR to replicate real-life situations in a controlled, less overwhelming manner. It's particularly beneficial for teaching social, communicative, and practical life skills in a secure environment. Floreo's simulated interactions offer a practice platform for users with autism, helping them develop skills transferable to everyday life. Both Unfear and Floreo exemplify how adjusting sensory inputs and offering flexible learning environments can be revolutionary for those with ASD.

Cybersickness

Motion sickness and nausea remain significant challenges in the mass adoption of virtual reality, both for consumer and industrial applications. One key issue is proprioception disorientation, which arises when there's a mismatch between where you perceive your limbs to be and their actual spatial position in the virtual environment. Recent research led by the University of Waterloo sheds light on why some individuals are more susceptible to VR-induced "cybersickness" than others. The study found that the perception of vertical orientation could shift after engaging in high-intensity VR experiences. This sensory adjustment significantly influences the severity of cybersickness. The findings could help VR developers create more comfortable and adaptable experiences by understanding the relationship between sensory reweighting and cybersickness susceptibility. In another study, researchers found that incorporating music into VR experiences can mitigate symptoms of cybersickness. Both joyful and calming music were shown to reduce the intensity of nausea-related symptoms, with joyful music having a particularly significant impact on reducing the overall intensity of cybersickness. These research developments offer promising avenues for reducing barriers to VR adoption, potentially leading to more personalized and enjoyable virtual experiences for users.

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"Visiting" Pregnancy

Due to her age, Lauren was unable to safely carry her pregnancy herself. Instead, her daughter was growing in an artificial womb at a specialized facility. The high-tech womb was calibrated to Lauren's own heartbeat and voice via a monitor that she wore at all times, surrounding the growing baby with the familiar, comforting sounds of its mother. The artificial amniotic fluid was even infused with Lauren's natural scent through a filtering process.

Today, Lauren is preparing to "visit" her pregnancy. She dons a state-of-the-art haptic suit, designed to simulate the physical sensations of pregnancy. The suit gently expands around her abdomen, mimicking the gentle pressure and movements of a growing baby. As the virtual nursery flickers into view, Lauren gasps. It was a line-for-line re-creation of the room her husband Eli was assembling at home, down to the plush rainbow rug and decaled quotes from her favorite children's books.

As Lauren settles into the metaverse experience, the suit adjusts snugly around her midsection, gently applying pressure to simulate the swell of pregnancy. She runs her hands along the warm, taut skin, marveling at how real it feels. Lauren feels a sudden thump and lays her hand on her belly. Her daughter is kicking up a storm today.

The haptic suit is just one part of the experience. The headset she wears is pivotal, not just visually, but also in altering Lauren's sense of smell to mirror the acute olfactory sensitivity typical in pregnancy. Scents are intensified, creating a vivid and authentic sensory experience. Furthermore, the headset induces psychological states akin to those of pregnancy, fostering a deep emotional bond between Lauren and her unborn child.

As Lauren walks through this virtual world, she speaks softly, knowing that her baby, though miles away in its artificial womb, can hear her. She sings lullabies, tells stories, and shares her hopes and dreams for their future together. Each word, each note of her song, is transmitted back to the womb, enveloping her baby in a warm embrace of mother's love.

EXPERIENCING IMMERSIVE WORLDS

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World Building on Blockchain

Advocates of the metaverse and blockchain share a core principle: decentralization. In the metaverse, this manifests as an open network of interconnected virtual worlds as opposed to closed, proprietary platforms. Some advocates argue that when built on blockchain, the metaverse can offer true digital ownership through NFTs, by allowing users to own, trade, and monetize virtual assets like land and avatars. Blockchain's transparent and immutable record-keeping lends credibility to digital ownership claims, while its interoperability allows assets and user profiles to carry seamlessly across metaverse environments. Examples like The Sandbox demonstrate this in practice—users can build, own, and sell their game creations through a dynamic, collective ecosystem. Other platforms like Hyperfy and Voxels, both running on the Ethereum blockchain, provide tools for users to design, construct, and trade entire worlds they own. This fusion of blockchain and the metaverse not only democratizes virtual space but also enables a more trustworthy and interconnected digital reality.

While the idealized vision of the metaverse and blockchain both emphasize decentralization, it's worth noting that many platforms, like Meta's proposed metaverse, may operate as closed ecosystems.

Events in the Metaverse

The metaverse shows promise as the next frontier for virtual experiences by creating immersive 3D environments mirroring real-world settings. Gaming, an early adopter of shared digital spaces, has expanded its virtual horizons beyond gameplay into events and social interactions. Games like "Roblox" and "Fortnite" have been pioneers, transforming their platforms into concert venues for top-tier artists, creating a new paradigm for live performances. In 2023, Decentraland hosted its second Metaverse Fashion Week, featuring over 60 fashion brands, including heavyweights like Balenciaga, Adidas, and Coach. While this event showcased the allure and possibilities within the metaverse, it also cast light on its current developmental infancy, evidenced by the participant feedback that spoke

to feelings of solitude, the complexity of navigation, and a deficiency in compelling content—revealing a stark contrast between the high ambitions of brands and the actual user experience. The concept of a metaverse festival has also been embraced by Coachella 2023, in partnership with "Fortnite." This collaboration introduced a new dimension to music festivals, combining iconic Coachella elements with the interactive and boundless nature of the "Fortnite" universe. Weverse has become a central hub for virtual K-pop events, where fans can engage with their favorite idols' avatars in a digital concert setting. This virtual space not only hosts concerts but also fosters fan interactions, proving that the metaverse can indeed re-create the vibrancy of live events in a digital format. As these digital spaces evolve, the focus must shift toward user experience to ensure the metaverse can fully realize its potential as a platform for communal and interactive events. Converting isolated solitary activities into bonded social occasions remains contingent on platform maturation.

AR Lenses and Filters

AR lenses overlay real-time digital information onto the physical world. Simple AR filters and lenses have long been a staple of social media, enabling users to add digital enhancements to their faces in real time. But these playful features are just the beginning; AR technology is becoming more sophisticated by leveraging generative AI. Snapchat's Cosmic Lens feature is a case in point, for using generative AI to transform the user's environment into an animated cosmic backdrop. Filters like TikTok's "Bold Glamour" echo this trend, offering hyperrealistic effects with the help of AI. Furthering the integration of AR into daily life, Snapchat is now streamlining the user experience by introducing intelligent recommendations for lenses based on environmental context—such as the weather or the time of day—using advanced visual recognition and API integration. Snap has also announced plans to introduce AR mirrors in retail stores, allowing customers to see how clothes would look on them in Nike stores and in Men's Wearhouse locations without the

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need to change outfits. This effort is part of a broader move to integrate AR technology into the physical world, including at music festivals and even in vending machines. Brands like Ikea are also leveraging filters to enhance the customer's shopping journey at home. Using smartphones' lidar sensors, Ikea's AR tools allow customers to replace their existing furniture with detailed 3D models of new items. Similarly, retail giants Walmart and Amazon have successfully adopted AR to enable customers to visualize products in their own space before making a purchase, whether it's placing furniture or trying on glasses.

Holograms

Holography is a technique that records and displays objects in three dimensions, making them either stand still or move just like real objects. It's more than just a 3D picture; it can show every detail of a person's face or body in motion. This capability is becoming increasingly important for the future of augmented reality and virtual reality, particularly as we look to populate the metaverse with realistic avatars and environments. The

fusion of holograms with deepfake technology and synthetic media is paving the way for their use in everyday settings. Already, holography has enabled the creation of virtual concerts featuring past celebrities, and it holds the potential for production companies to bring popular synthetic characters and celebrities into our physical world as interactive entities. For instance, Ukrainian President Volodymyr Zelenskyy harnessed this technology for remote addresses across European cities using Canadian firm ARHT Media's state-of-the-art holographic technology, speaking from within his country amid conflict. The Hologram Zoo in Brisbane, Australia, presents a new way for people to experience wildlife. Here, holograms create lifelike depictions of animals, such as a herd of elephants charging toward and then seemingly through the spectators. This attraction makes holographic technology more accessible by significantly reducing costs, thus avoiding the ethical dilemmas of captive wildlife exhibits and offering an immersive educational experience.

ARHT Media has also introduced Capsule, a versatile holographic display designed to shine in any lighting condition, perfect for captivating audiences in cinema lobbies. This technology allows live hologram presenters to interact with people across distances, and it can showcase prerecorded content that engages viewers through interactive touchscreens. The potential applications are vast, ranging from advertising and immersive trailers to live talent meet-and-greets and product demonstrations. In the pursuit of more lifelike holographic projections, researchers have developed three-dimensional scattering-assisted dynamic holography (3D-SDH), which greatly enhances the depth resolution of 3D images. This cutting-edge method could revolutionize how we interact with virtual environments by offering a much richer, more detailed experience.

Real Estate in the Metaverse

Real estate in the metaverse is emerging as a new digital frontier where people can buy, develop, and experience virtual land and

Metaverse real estate offers long-term prospects for virtual land as spaces for community, commerce, and creativity, free from physical limitations.

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properties. Though still nascent, metaverse real estate is drawing interest from individual investors, corporations, and even real world real estate companies. In metaverses like The Sandbox and Decentraland, virtual land is sold as NFTs on blockchain. Parcels near popular virtual spaces or owned by celebrities can sell for hundreds of thousands of dollars or more. The overall metaverse real estate market is estimated to be worth over $1 billion. Corporations like Adidas and Atari, and celebrities like Snoop Dogg have purchased virtual land to host branded experiences, digital HQs, stores, and spaces. One buyer paid $450,000 to become Snoop's neighbor in the virtual world.

Some companies are taking it further by developing conceptual virtual homes and structures with architectural firms. Everyrealm, a metaverse technology and infrastructure company, has partnered with artists like Misha Kahn and Daniel Arsham to create an imaginative collection of digital homes called The Row. These futuristic virtual abodes feature melting, Salvador Dali-esque architectural angles and dreamlike floating spheres. Mirroring real world tactics, traditional home builders like KB Home have also established presences to showcase model homes. They aim to reach new demographics and drum up interest in real-life offerings. While speculative now, advocates see long-term potential for virtual real estate as immersive spaces for community building, commerce, and creativity. The metaverse provides freedom from physical constraints to create imaginative environments.

Worlds for Purpose

The metaverse is being harnessed for significant causes, transcending beyond a mere digital escape into a platform for meaningful global action. The World Economic Forum has taken a pioneering step by introducing the Global Collaboration Village in the metaverse, a collaborative effort with Accenture and Microsoft. This virtual space is dedicated to convening organizations to address, brainstorm, and act on global crises. It was revealed during the Annual Meeting 2023 in Davos, showcasing a tangible prototype that exemplifies the vision of a global community coming together in a digital realm. The village is structured to facilitate impactful interactions, with areas such as a Virtual Congress Centre akin to a digital town hall for hosting various future meetings and sessions. It also comprises immersive collaborative centers that serve as hubs for engaging storytelling and spreading the Forum's insights on critical issues, fostering a collaborative spirit aimed at real-world change. Partners of the Forum have the opportunity to carve out their virtual campuses, allowing them to rally their stakeholders and drive forward initiatives to solve worldwide problems. Simultaneously, The Sandbox's Wistaverse has emerged as a pioneering virtual protest platform, offering a secure space for worldwide activism and education. Its goal is to empower users to engage in nonviolent protest and discourse, removing the risks associated with physical gatherings.

Worlds for the Enterprise

Major tech companies are racing to make virtual collaboration a reality for enterprises. Microsoft is integrating Mesh directly into Teams to allow coworkers to join 3D meetings as avatars, sans VR headset. This aligns Mesh with Microsoft's everyday work tools after an initial failed launch as a standalone developer platform. Mesh now focuses on enabling Teams' 320 million users to have more engaging meetings using spatial audio, simulated environments like a virtual lake house, and AI features like virtual whiteboards. Microsoft is betting its massive user base will propel adoption despite strong startup competitors like Jugo and Frame also offering immersive meeting solutions. Jugo similarly provides 3D collaboration spaces for remote teams to brainstorm ideas on virtual whiteboards or conduct meetings as customizable avatars. Frame uses volumetric video to generate photorealistic avatars, targeting enterprises seeking hyperrealism. These companies aim to make remote collaboration more natural by simulating the nuances of in-person interactions. Though still early, some companies are

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piloting these technologies to enable hybrid teams to work together more intuitively. Microsoft's integration into Teams gives it a distribution advantage, but the space remains competitive as startups offer differentiated features around customization and realism.

Play-to-Earn and Virtual Marketplaces

Play-to-earn games fuse gaming and economics in metaverse environments by enabling players to generate real-world value through virtual gameplay. Leveraging blockchain technology, these games establish in-game assets like fantasy creatures or virtual land as tradable NFT commodities. This diverges from traditional in-game items, where items lack external utility or ownership portability after usage. Instead, metaverse games facilitate exchange of digital goods for cryptocurrency or fiat money. "Axie Infinity" is a pioneer in this space, where players breed, raise, and battle fantasy creatures called Axies, with in-game transactions involving Ethereum-based cryptocurrencies. "My Neighbor Alice'" also offers a blockchain twist to casual farming simulators, where players can buy virtual land and earn rewards through daily activities and can use their NFTs to decorate their virtual space. The well-known game "Minecraft" is also considered a virtual economy, allowing players to trade items, and this concept of in-game value is amplified in the metaverse.

Marketplaces like OpenSea act as trading hubs for these virtual goods, allowing the digital assets from various metaverse games to be bought and sold, underpinning the economic potential of play-to-earn games. Exponential growth potential looms as financial institutions like JPMorgan strategically support metaverse transaction platforms like Tilia. Seamless fiat currency interchangeability can further expand adoption and capital inflow. Just as physical economies rely on agreeing on currency, unit of account, and other standards, maturing these fundamentals will shape the trajectory of blockchain-based virtual marketplaces. The fusion of play and profitability through ownership of digital goods represents merely the first stage.

Players can earn real-world value in virtual environments through gameplay, with blockchain allowing for the acquisition and trading of digital assets such as NFTs.

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Cosplay Category Announcement

Welcome to the 2027 Super Cosplay Con—the world's premier cosplay convention where physical reality converges with the virtual multiverse. This year's Super Cosplay Con is enabled by augmented reality glasses that project 3D avatars and effects, blurring the lines between the real and virtual worlds. The costume contest categories reflect the multifaceted experiences of Super Cosplay Con attendees.

The Digital Division honors stunning costumes crafted entirely from interoperable assets across different metaverses. Contestants proudly display their creativity in mixing and matching skins, accessories, and effects from platforms like Cryptoverse, Mara, and VRealms.

The Physical Division shines the spotlight on traditional handcrafted costumes made with real-world materials. Cosplayers spent months bringing elaborate costumes to life with fabric, foam, paint, and painstaking detail. Their devotion to practical craftsmanship is on full display.

The Mixed Reality Division highlights the best blended costumes—real-world apparel taken to the next level through digital avatars and AR enhancements viewable through attendees' smart glasses. A knight's armor appears charred from virtual dragon fire, while a wizard's cloak billows from fabricated wind.

Hope to see you at Super Cosplay Con!

METAVERSE INFRASTRUCTURE

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Interoperability

Interoperability is fundamental for the envisioned metaverse: Akin to the universal standards of today's internet, it would allow seamless data exchange and interaction across various systems and technologies. This functionality is essential to enable asset transfer and identity management across diverse digital and physical spaces, and its importance is highlighted in the World Economic Forum's 2023 briefing paper, "Interoperability in the Metaverse." As companies advance in integrating within their platform silos, the challenge shifts to connecting these silos to meet the growing demands for cross-platform 3D assets. Facilitating this effort, the Metaverse Standards Forum, formally incorporated in April 2023, brings together a consortium of organizations to foster interoperability, not by creating standards themselves but by producing technical reports, best practices, and guidelines. This collaboration is crucial for developing the necessary standards to build a cohesive and functional metaverse. Businesses have made significant progress in integrating various elements within their individual platform silos. However, the forthcoming challenge lies in interlinking these silos themselves. This necessity will grow more pronounced as enterprise applications converge and as the demand for cross-platform 3D assets increases.

Government Investment

Government investment in the metaverse is emerging as a key strategy for fostering economic growth and innovation, with several nations recognizing the potential of this digital space. By supporting metaverse infrastructure, governments aim to create new jobs, attract businesses, and enhance the lives of their citizens. Dubai's Metaverse Strategy is a prime example, where the city plans to become a global hub for the blockchain and metaverse sectors by 2030. This strategy aims to support over 40,000 virtual jobs and increase the number of blockchain companies fivefold, as part of the UAE's broader vision to create one of the smartest cities worldwide. Similarly, China is focusing on the metaverse as part of its technology strategy. The Ministry of Industry and Information Technology (MIIT) is looking to set standards for the metaverse industry, which they see as crucial for promoting a healthy and orderly market development. China's stance is to address the challenges in the metaverse sector—such as the lack of clear definitions that can lead to market speculation—by providing standardization and guidance. South Korea has also made significant strides by investing 24 billion Korean won ($18.1 million) in a fund dedicated to metaverse initiatives, recognizing the difficulties local companies face in securing private investments due to the risks associated with emerging technologies. The government's support extends to helping with mergers and acquisitions and ensuring domestic firms can compete on a global scale. In a tangible demonstration of their commitment, Seoul launched a digital twin in the metaverse with a substantial government investment, underscoring the importance of the metaverse in urban and social development.

Developer Tools and Application Building Blocks

The creation of the metaverse is driven by a diverse array of developer tools, many of which are open source to align with the metaverse's principles of inclusivity and community-driven development. This democratic approach to building virtual spaces is crucial, as it allows for a metaverse that is crafted by its users, rather than solely by large corporations. This method of construction by a passionate user base contributes to the metaverse's unique and innovative nature. A prime example is the "Roblox" platform where a majority of creators are under 18 years old. These young developers use Roblox Studio to craft their own games, employing Luau—a version of the programming language Lua. The platform facilitates creativity and entrepreneurship, allowing these young creators to earn through game passes and microtransactions, a testament to the economic potential within the metaverse. Tools like the Ethereal Engine (XREngine) support this creative explosion, offering open-source capabilities for crafting immersive and interactive 3D experiences.

METAVERSE INFRASTRUCTURE

Platforms like Webaverse extend the creative frontier further into decentralization, allowing developers to build and interact with dApps within the metaverse. What's unique about the metaverse developer tools is how they empower builders, many of whom are young and passionate users, to take ownership of their creations. This participatory culture is fueling the metaverse's growth into a rich, vibrant digital ecosystem where innovation is constant and opportunities are vast.

Interdevice Synchronization

Interdevice synchronization is a vital component in constructing the infrastructure of the metaverse, as it guarantees a unified and real-time interaction across various devices in AR and VR settings. This has been a significant hurdle to overcome. In environments like online gaming and virtual workspaces, where multiple users engage in a shared virtual space, synchronization is key to ensuring a smooth and coherent experience for all participants. It is also crucial for accurately replicating user movements within the virtual realm, thereby enhancing the sense of immersion and averting problems such as motion sickness. To address this challenge, researchers from MIT and Microsoft developed the Ekho system, which synchronizes audio streams across different devices. The system works by embedding subtle white noise sequences into the audio stream sent from the cloud server, which are then picked up by the audio sensors in the player's controller or other devices. Ekho's core mechanism involves continuously monitoring the time lag between the sent and received audio streams through these white noise markers. When a delay is detected, Ekho promptly adjusts the timing, aligning the streams to achieve near-perfect synchronization. This advancement by MIT and Microsoft researchers marks a significant leap forward in enhancing the overall quality and realism of virtual experiences in the burgeoning field of the metaverse.

5G for the Metaverse

The advancement of 5G technology is required for the metaverse to reach its full potential, as metaverse applications demand high bandwidth and reliable networks to process and transmit extensive visual data for immersive experiences. The rollout of 5G by major US carriers like AT&T, Verizon, T-Mobile, and Dish Network is a game-changer, offering up to 10 times the bandwidth of 4G, with speeds up to 10 gigabits per second, lower latency, and greater reliability. These features are key to avoiding disruptions in the metaverse, ensuring a seamless alternate reality experience. China, as an early adopter and implementer of 5G, exemplifies the impact of this technology on the development of virtual and augmented reality applications. With a large user base in VR and AR, China is quickly becoming a leading market in this field. The symbiotic relationship between 5G and the metaverse is evident here; the metaverse benefits from 5G's widespread access, reliable connectivity, and the ability for XR devices to offload processing to the edge of the network. This mutual enhancement, evidenced in China's rapid growth in VR, is paving the way for more comprehensive and globally accessible metaverse experiences.

For a seamless metaverse with low latency, it depends on network connectivity, making 5G a crucial enabling technology.

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BIOENGINEERING

Future Today
Institute

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TOP HEADLINES

AI breakthroughs are set to make this year a turning point for biotech, CRISPR, and synthetic biology.

01 Lab-Grown Meat Is Going Mainstream

Cultivated meat and synthetic dairy are emerging as sustainable and ethical alternatives to traditional animal products, and in 2024 production will start to scale.

02 CRISPR Will Treat Disease

US and UK regulators have approved the first CRISPR therapy, marking a significant step in gene editing's potential to cure genetic diseases.

03 Millions of New Materials Discovered

A new AI system from Google DeepMind predicted 2.2 million novel materials, signaling big changes ahead for batteries, computer chips, and more.

04 AI Transforms Biology Today; Biology Powers Computers Tomorrow

Scientists created organoid intelligence, a new biocomputing field using brain cells for AI, promising major efficiency gains over traditional computer systems.

05 We Aren't Prepared for a Cyber-Bio Attack

Cyberbiosecurity has emerged as a crucial unmet need at the intersection of AI and life sciences, with no formal oversight yet established.

STATE OF PLAY

Brace yourself for uncharted impacts. This could be a breakthrough year for biotechnology.

In the past year, AI breakthroughs have accelerated the convergence of biology, information systems, and advanced platforms, with the potential to fundamentally transform businesses and societies. While today, our focus is on generative AI, very soon that focus will shift to generative biology: Here, AI models will decipher the complexities of biology, leading to the creation of novel molecules, drugs, materials, consumables, and living organisms.

Our orientation to biology and the living world will change in the near future as CRISPR products, in the form of novel drug therapies and new foods, enter the market. Soon, we will no longer be constrained by existing materials to manufacture batteries, clothing, or buildings.

Lab-grown beef, chicken, and fish will scale, making it possible to consume meat without slaughter. Through cellular reprogramming, we could start to reverse the aging process. And we're on the brink of new fertility treatments that will challenge our ideas about parenthood.

These shifts will fundamentally alter our relationship with biology and the natural world, but we lack comprehensive policies to navigate them. While biotech promises to reshape our world, it also presents unprecedented risks, underscoring the need for preparedness and governance.

KEY EVENTS

JUNE 13, 2023

Pushing Limits of Embryo Models
Israeli, UK, and Chinese research teams
advance embryo models beyond legal
limits, prompting ethical debates.

DECEMBER 8, 2023

FDA OKs Gene Therapy for Sickle Cell
Casgevy becomes the first approved
commercial gene-editing treatment
using CRISPR technology.

FEBRUARY 6, 2024

GMO Seeds Sold Direct to Consumers
The FDA gives purple tomatoes, genetically
enhanced to be more nutrient-dense,
approval for home gardening.

NOVEMBER 29, 2023

AI Unlocks New Material Secrets
Google DeepMind's AI predicted structures of
over 2 million potential new materials, potentially
enhancing technologies like batteries, solar
panels, and chips. Scientists could create around
400,000 of these materials in labs soon.

JANUARY 18, 2024

Universal Cancer Vaccine Trials
Cancer patients in the UK receive
the first dose of a new mRNA
therapy designed to help the body
recognize and fight cancer cells.

LIKELY NEAR TERM DEVELOPMENTS

RAPID ACCELERATION

The rapid integration of artificial intelligence into bioengineering is catalyzing unprecedented innovation. The near future will see significant changes to traditional industries such as meat, dairy, textiles, and pharmaceuticals, while advancements should pave the way for sustainable solutions in carbon capture, plastics recycling, and biodiversity enhancement. Near-term breakthroughs in healthcare will lead to cataclysmic, long-term disruption. Leaders should deepen their understanding of bioengineering's vast potential and associated risks, enabling them to spearhead innovation in products and services, streamline processes, improve materials, and achieve cost efficiencies. This convergence also opens up new avenues for collaboration, allowing companies to explore untapped markets and forge strategic partnerships that can drive forward their competitive edge.

CRISPR's Emerging Economic Impact

The size of the global market for CRISPR technologies and their associated products is projected to exceed $4 billion by mid-decade. In the US alone, CRISPR could contribute $19 billion to GDP by 2032.

Life Extension Backlash

Life extension breakthroughs promise longer lives for some, yet they will strain social services, pensions, and other support systems for the elderly, challenging our preparedness for an aging population.

Supply Chain Disruption

In the next year, new materials poised to improve shipping's environmental footprint may disrupt traditional supply and cold chain operations dependent on outdated tech, posing significant threats to established companies.

GMO Misinformation

A new GMO backlash looms as public misinformation persists, with many unaware that the latest GMOs aim to boost produce and grains with enhanced nutrients, not just modify them for convenience or yield.

Regulatory Pressures

Federal Trade Commission actions spark fears of stifled innovation due to limits on scaling therapies via acquisitions, while the US Inflation Reduction Act ushers in a harsher pricing climate, impacting the biopharma industry's future reimbursement strategies for innovations.

Stark Health Divide

Biotech will revolutionize health care with novel drug therapies, yet their inaccessibility to developing economies risks creating a stark health divide, exacerbating global health inequalities.

11 MACRO SOURCES OF DISRUPTION

Technology	Media & Telecom	Demographics	Environment	Government	Public Health	Education	Geopolitics	Infrastructure	Economy	Wealth Distribution

WHY BIOTECHNOLOGY TRENDS MATTER TO YOUR ORGANIZATION

Biotech Is a General Purpose Technology

As a modern "general purpose technology," bioengineering has the potential to influence an entire economy and alter society through political, economic, and social structures. By 2030, most people in developed economies will have used or consumed a product created with a bioengineering technology.

Biotech Will Change Your Value Network

Biotech advancements will transform the value network for businesses. Without active monitoring, disruptors may emerge, threatening established companies' capacity to create value and maintain their competitive edge for market share, investment, and talent.

Advancements Should Result in Optionality

Advancements in synthetic biology, CRISPR, AI, and engineering are opening up new opportunities across health care, pharmaceuticals, agriculture, food and beverage, beauty, chemicals, sustainability, energy, and materials production.

AI-Bio Convergence Requires New Strategy

The convergence of AI and biology will impact every business. Leaders will need a better understanding of bioengineering's potential and risks, so they can innovate products and services, develop processes, enhance materials, reduce costs, and seek out new partners and customers.

Disruption Is on Your Near-Term Horizon

Near-term disruptions in the traditional meat, dairy, textile, and pharmaceutical industries are imminent, with advancements offering new options for carbon capture, plastics recycling, and enhancing biodiversity, signaling a pivotal shift in environmental management.

Businesses Need New Policies

In response to bioengineering advances, businesses must develop policies that embody their values, ethics, and culture, such as the use of genetically enhanced ingredients, insurance coverage for novel genetic therapies, whether and how to promote genetic privacy, and more.

WHEN WILL BIOTECHNOLOGY DISRUPT YOUR ORGANIZATION?

Forecasted Time of Impact

0-4 YEARS	5-9 YEARS	10-14 YEARS	15+ YEARS
Medical Devices	CO_2 Capture Farming	Oil/Petroleum Sector	Computing
Vaccines	Ranching	Electricity	Life Extension
OTC Medications	Health Diagnostics	Aerospace	Off-Planet Exploration
Poultry Farming	Recycling	Cold Chains	
Defense	Chemicals	Living Materials	
Beauty	Fast Fashion		
Drug Development	Consumer Packaged Goods		
Textiles	Construction & Building Materials		
Luxury Fashion	Paints & Coatings		
	Data Storage		
	Grain		
	Automotive		

WHEN WILL BIOTECHNOLOGY DISRUPT YOUR ORGANIZATION?

Advancements in bioengineering will disrupt every industry, to some degree, within the next two decades. The Future Today Institute categorizes bioengineering as a "general purpose technology." Like the steam engine and internet before it, bioengineering has the potential to influence an entire economy and to alter society through political, economic, and social structures. For most industries, it's not a matter of if these trends will disrupt their futures but when.

Several factors are driving the momentum of bioengineering trends and the probable timing an industry will be disrupted:

Scaling
While the pace of innovation is fast across the spectrum of technologies, it takes time for a promising new biotech development to scale beyond the lab. Scaling requires discipline, patience, effort, and time.

Costs
Bioengineering research is still costly, though the price of components, equipment, and materials drops every year. Once a disruptor can make a product cheaper with bioengineering rather than traditional production, it will push faster into the mainstream. Advancements in technology will eventually bring down costs of production as we've seen in other fields, such as computing.

Constraints on adoption
Even if a technology is maturing, constraints on its adoption can hinder its influence in an industry. For example, a business may refuse to adopt an alternative bioengineering technology because it challenges a proven, successful strategy.

Regulations
The pace of technology advancement typically far exceeds any changes to regulation. Bioengineering is unique in that regulation exists, but products and processes are treated differently in every country. Regulatory and policy uncertainty could accelerate or stifle growth.

Media mentions
Increased awareness and enthusiasm can influence the momentum of a technology, even when there's been no real breakthrough. Media bursts related to bioengineering will drive momentum, especially if those stories are favorable and—importantly—easily understood by the general public.

Public perception
How the public understands, and responds to, bioengineering advancements will create or quell demand. This is especially true for food and beverage, consumer packaged goods, beauty and fashion, over-the-counter medicines and vaccines, and new therapeutics.

R&D developments
The pace of new research breakthroughs can't be scheduled to coincide with a board meeting or earnings report. There are factors that can improve the likelihood and speed of new discoveries (funding, quality and size of staff, access to resources). We closely monitor R&D developments but treat them as wild cards.

OPPORTUNITIES & THREATS

Threats

There is no alignment on a global framework governing bioengineering. As a result, you can anticipate geopolitical conflict stemming from the development and use of emerging bio-based technologies in the years to come.

Unresolved IP and patent issues in biotechnology raise serious concerns about how patenting practices could hinder biotech development across various countries.

While new agricultural methods may benefit the environment, they pose threats to local communities in economies still reliant on traditional farming practices.

CRISPR therapies may not be universally accessible, potentially deepening global health divides and exacerbating current disparities, leading to worsened conditions and future conflicts.

Engineering novel organisms and using techniques like germline editing risks uncontrollable cascading effects in nature, potentially creating invasive species or pathogens, turning a lab accident into an ecological disaster.

Opportunities

In the coming decade, biotech advancements will cause leaders to confront their core beliefs about their business models, products, and services. In the meantime, it's imperative that businesses seek out new partnerships, develop new pipelines for talent, and align stakeholders on the moral and ethical uses of engineered biology.

Because bioengineering has been evolving over decades, it may seem premature for action, but its advancements will compound. Like AI, which grew quietly before becoming essential, bioengineering will soon be integral to operations. Leaders paying attention to its progress and harnessing strategic foresight can gain first-mover advantages.

Biotech companies always face capital needs, particularly amid sector-wide valuation challenges. Streamlining R&D, general, and administrative expenses—as well as exploring new financing options, and considering mergers with other biotechs—can help them navigate the current market landscape.

Businesses should start exploring white spaces now. Where are the opportunities for innovation and growth? What might threaten the organization's ability to thrive? Where are there downstream risks to partners or customers? Businesses that seek out and anticipate near-term developments will gain a competitive advantage.

Generative biology (genBio) will unlock new ways to develop medicines, food, agricultural systems, beauty and skincare products, textiles, packaging and building materials, and more. Leaders should develop scenarios for using and scaling these genBio systems, processes, and products.

INVESTMENTS AND ACTIONS TO CONSIDER

1

As companies consider AI's impact on their workforce, they are neglecting to focus on future demands for individuals skilled in both AI and biology. Companies across various sectors should proactively develop insights into their future workforce requirements and start establishing the necessary talent pipeline now.

2

As VC investment floods into groundbreaking biotech platforms this year, companies must distinguish themselves by clearly defining their uniqueness. Also crucial is broadening their focus from rare to major unmet medical needs, ensuring a solid value proposition to secure crucial VC funding for drug approvals.

3

As the biotech ecosystem evolves, life sciences and other companies will need to undertake a new digital transformation that includes AI. This should include the creation of a long-term strategy, an expanded value network map, and a comprehensive execution plan to stay competitive and innovative.

4

The AI-bio convergence will spark myriad innovations and demand unprecedented agility from companies. Leaders must empower their organizations to experiment with new products and processes, and ensure that they shape their own futures rather than being compelled to adapt to external innovations or react to regulatory shifts.

5

The uncertain regulatory landscape offers a unique opportunity for business and government to collaboratively envision the future. Regulation is reactive. Stakeholders can proactively evolve frameworks to address safety, update IP and copyright processes, align on commercialization strategies, and thwart misinformation.

6

To stay competitive, companies must use strategic foresight to understand how the evolving biotech ecosystem could impact their existing products and processes. Leaders should prioritize monitoring, acting, and agile decision-making in order to adapt to the AI-bio convergence.

CENTRAL THEMES

Gene Editing Realizes Its Promise

CRISPR's journey to commercial success has been a marathon, not a sprint. For more than a decade, the gene-editing technology faced many hurdles, from technical challenges to patent disputes to regulatory approval, slowing its path to practical applications. Finally, in 2023, CRISPR's promise crystallized with the approval of Casgevy, a first-of-its-kind therapy for sickle cell disease in the UK and US. This landmark therapy, which deactivates a specific gene, highlights CRISPR's ability to disable genes with precision. More importantly, with government clearance and a real-world use case, Casgevy opened the door to a vast array of possibilities for gene editing and other biotechnology applications. However, as CRISPR therapies move toward broader application, challenges remain: namely, the complexity and cost of treatments, accessibility issues, and public trust. Despite these obstacles, CRISPR's trajectory toward commercialization marks a significant milestone—though the marathon continues.

AI and Biology Are Converging

Increasingly, AI is being used in biological systems. Scientists are no longer limited by a traditional human team's speed: New AI models now accurately predict biological structures, a capability that will accelerate scientific research that used to take decades. The AI-bio convergence extends into computing itself, and researchers are exploring the creation of biology-powered machines. These innovative systems promise to be faster, more efficient, and consume significantly less energy than traditional computers. Organoid intelligence aims to use human brain cells in a new type of computer. Programmable DNA computers execute complex operations through molecular manipulation. Some researchers believe this fusion of computers and biological processes is the real future of artificial intelligence; both are important because they offer novel approaches to problem-solving and unlock new forms of creativity. Biological computers potentially open up unprecedented opportunities to improve compute power, data storage, and sustainability.

Businesses and Governments Aren't Prepared

Businesses and governments need to catch up as AI and biology converge. Biotech fields are making discoveries that not only deepen our insight and create new options—they also introduce novel methods to alter biological systems, with outcomes that remain unpredictable. Such progress presents vast opportunities for investment and for businesses to meet their ESG goals. However, it poses challenges for incumbents in supply chain management, agriculture, consumer packaged goods, health, and biosciences that may not see their value networks changing early enough to take action. Cyberbiosecurity is a growing and unmet need, as increasingly companies will need to protect the biotech ecosystem from unauthorized access, damage, attack, and other threats. As new biotechnologies emerge, a lack of alignment on purpose and policy could result in the situation we see today with AI. Without strategic foresight to prepare for the future, the potential risks associated with biotechnological advancements could surpass those of AI, underscoring the urgent need for readiness.

ONES TO WATCH

Dr. Amy Trejo, director of R&D and responsible materials innovation at Procter & Gamble, for leveraging bioengineering for sustainability in the consumer packaged goods space.

Dr. Arthur Levin, distinguished scientist at Avidity Biosciences, for engineering a new RNA platform that delivers therapy to previously inaccessible tissue and cell types.

Dr. Cheryl Cui, CEO of Bota Biosciences, for launching a new type of engine for biological programming and discovery.

Chris Abbott, CEO of Pivot Bio, for scaling sustainable biotech solutions to meet global agricultural challenges.

Dr. Demis Hassabis and **Dr. Shane Legg,** co-founders of DeepMind, for their groundbreaking AI inventions that predict biological structures and combinations.

Didier Toubia, CEO and co-founder of Aleph Farms, for achieving the world's first government clearance to produce and sell cultured beef.

Dror Bin, CEO for the Israel Innovation Authority, for scaling innovation resources in biotech and other critical technologies.

Eben Bayer, co-founder and CEO of Ecovative, for innovating business models to integrate mycelium technology into the production of food and materials.

Dr. Emily Leproust, CEO of Twist Bioscience, for breaking new ground in high-throughput synthesis and sequencing of DNA.

Dr. Gaurab Chakrabarti, CEO of Solugen, for decarbonizing the chemicals industry.

Dr. Hal Barron, Dr. Rick Klausner, and **Hans Bishop,** founders of Altos Labs, for leading a new effort on cellular rejuvenation programming to reverse the human aging process.

Dr. J. Craig Venter, CEO of JCVI and serial entrepreneur, for advancing the fields of synthetic biology and genomic research.

Dr. Jason Kelly, co-founder and CEO of Ginkgo Bioworks, for scaling genetic engineering to produce bacteria with a wide variety of applications.

Dr. Jianmin Fang, co-founder and executive director of RemeGen, for overseeing one of the largest partnership deals between a Chinese biotech company and a Western company (Seagen) in history.

Josh Tetrick, co-founder and CEO of Eat Just, for commercializing cultured meat in the US and Singapore.

Dr. Kimberly Smith, R&D chief at ViiV Healthcare, for her work to end the HIV epidemic through her visionary practices and innovative approach to clinical development.

Dr. Lisa Dyson, founder and CEO of Air Protein, for her work developing food from carbon dioxide.

Dr. Mary Maxon, executive director of BioFutures at Schmidt Futures, for developing and leading a new program to maximize the potential of biotech for a circular bioeconomy.

Matthew McKnight, general manager of biosecurity at Ginkgo Bioworks, for his role in advancing biotechnology for national security, public health, and pandemic preparedness.

Niyati Gupta, CEO of Fork & Good, for building and scaling new business models in food and agribusiness.

Dr. Noubar Afeyan, CEO of Flagship Pioneering, for inventing and building platform companies, each with the potential to transform human health and the planet.

Dr. Raymond Deshaies, senior vice president for global research at Amgen, for his work on a new frontier of small molecule design via RNA degradation.

Dr. Sarah Reisinger, chief science and research officer for DSM-Firmenich, for her continued work bridging the gap between R&D, technical requirements, and commercialization.

Dr. Yin Ye, CEO and executive director of BGI Group, for scaling the industrial application of cutting-edge biotechnology and genomics research.

IMPORTANT TERMS

BIOENGINEERING DOMAINS

Innovations in biotechnology are currently defined by five key areas: biomolecules, biosystems, biomaterials, biocomputing, and biomachine interfaces. Major breakthroughs in one field either reinforces or accelerates breakthroughs in the others.

Biocomputing
Biology is made up of code—and the goal is to harness that code for computing. DNA and RNA can be used as mediums for storing information and data processing. While traditional supercomputers use a lot of energy, heat up quickly, and require costly cooling centers to function properly, biological computing systems can perform computations without burning excess energy—and they are infinitely scalable.

Biomachine iInterfaces
Innovative new interfaces are connecting living organisms to computers for many different purposes, from restoring a stroke victim's ability to walk to someday controlling external computers simply using thought.

Biomaterials
It is now possible to replicate or improve on raw materials using bioengineering technology. One ex-

ample: a bioreplacement material that is produced sustainably, at a lower cost than traditional raw materials, and poses no harm to the environment.

Biomolecules (also known as omics)
A group of biological sciences collectively known as "–omics," including fluxomics (metabolic reactions in cells), metabolomics (chemical species involved in the reactions in cells), proteomics (the decoded product, or proteins), transcriptomics (the RNA created from each piece of genetic code), and genomics (the DNA code that drives cellular processes) is working to analyze the structure and functions of biological molecules that translate into the function and dynamics of an organism. Learning about and tinkering with the engineering of molecules (think: DNA, RNA) will lead to new therapeutics and innovative defenses against novel viruses, as well as alternatives to the ways we currently grow food.

Biosystems
Biology is complex. Scientists are applying engineering principles to understand and influence the pathways, connections, and interactions within biological systems. Developing new processes could lead to new opportunities to modify or even create cells, tissues, organs, and potentially complex networks like respiratory systems.

ADDITIONAL TERMS

Cas9 (CRISPR associated protein 9)
A special enzyme that can cut DNA sequences. Cas9 is part of the "molecular scissors" method of genome editing made possible by CRISPR.

Chimera
A living organism created by combining cells from at least two genetically different organisms.

Chromosome
A thread-like structure made up of a single length of DNA and found in the nucleus of each cell.

CRISPR (clustered regularly interspaced short palindromic repeats)
A naturally occurring genetic engineering tool found in bacteria that can be programmed to target specific areas of genetic code and to edit DNA at precise locations.

DNA (deoxyribonucleic acid)
A self-replicating two-stranded molecule, arranged as a double helix, that contains the genetic instructions used in the development, functioning, and reproduction of an organism.

Enzyme
A biological catalyst, usually a protein. Enzymes speed up the rate of specific chemical reactions in cells.

Ex vivo
Outside of cells or an organism.

Gain of function (GoF) research
Research intended to modify a biological pathway in a cell line or organism to enhance or increase certain biological functions.

Gene
The basic unit of heredity.

Genome
The complete set of DNA that makes up an organism.

Genome editing
Intentionally altering cells or organisms by inserting, deleting, editing, or otherwise modifying a gene or gene sequence.

Heritable genetic change
Altering genes in a way that results in changes that pass down through generations.

IMPORTANT TERMS

In vivo
Inside of cells or a living organism.

Induced pluripotent stem cells (iPSC)
Cells that have been reprogrammed back into an embryonic-like state with the potential to develop into other types of cells that can be used for thera-peutic or reproductive purposes.

Mutation
A change in a DNA sequence.

Off-target effect
Typically an unintended direct or indirect conse-quence of altering an organism.

Regenerative medicine
An emerging field seeking to repair or replace torn, defective, or missing tissue using stem cells, engi-neered cells, or biological processes.

RNA (ribonucleic acid)
A messenger chemical that carries instructions or translates the genetic code of DNA into structural proteins.

Stem cell
Nonspecialized cells that have the ability to develop into other types of cells with specialized functions.

Synthetic biology
A field of science rooted in both biology and engineering that seeks to redesign organisms, or design new organisms, to have new abilities.

AI AND BIOLOGY

AI AND BIOLOGY

Pharmaceutical Companies Invest in AI

Historically, scientists struggled to mine big biological data sets for insights using conventional statistical tools. With the spotlight now on AI, drug developers now see they're failing to capture the value of their important asset: their data. AI's potential to refine the often unpredictable process of drug discovery is significant, since even marginal enhancements can substantially improve the speed and efficiency of developing new drugs. Two years ago, DeepMind's AlphaFold made a notable breakthrough in predicting protein structures, an advancement that will soon revolutionize the process of identifying molecules with therapeutic potential. But the practical application of AI in drug development is already underway. AstraZeneca now uses reinforcement learning in 70% of its small molecules in development. London-based biotech startup E-therapeutics uses AI to design RNA molecules and algorithms to predict their likely activity, in an effort to thwart disease-causing genes. Investment bank Morgan Stanley projects that within the upcoming decade, the pharmaceutical industry could spend roughly $50 billion a year on AI to propel every stage of new drug development, from ideation to compound identification to clinical trial design and marketing.

Generative AI Gains Wide Acceptance

Just a few years ago, the pharmaceutical and life sciences industries weren't all that interested in investing in or using AI to automate and improve various processes. Last year, when genAI took center stage, that resistance started to fade, especially in the Asia-Pacific region where genAI startups are particularly active. Singapore's Integrated Health Information Systems entered a pivotal partnership with Microsoft and OpenAI, which will create a health care–specific GPT hosted on Azure. Once it's finished, this initiative aims to enhance the efficiency of health care workers by providing valuable insights and automating tasks. In Japan, the introduction of an advanced genAI tool is transforming the way doctors process extensive patient interviews. Tokyo-based Ubie is a startup that makes AI-based health care products, hospital SaaS products, and AI symptom checkers. As genAI technologies continue to evolve and integrate within the pharmaceutical and life sciences sectors, strategic shifts in how health care and medical research are conducted and managed will occur.

Text-to-Synthetic Compound: LLMs Automate Chemistry

While you were asking GPT-4 to write the lyrics for a rap song about avocados, researchers have been enhancing the capabilities of large language models to automate complicated tasks in chemistry. One such researcher is Philippe Schwaller, from the Swiss Federal Institute of Technology in Lausanne, whose team gave GPT-4 access to extensive databases of molecules, chemical reactions, and scientific research. They call the new system ChemCrow, and they're using it on a wide range of chemistry challenges, including drug synthesis and cost calculation. ChemCrow successfully devised a practical plan for synthesizing atorvastatin, a drug for high blood cholesterol. On average, Chem-Crow achieved over 9 out of 10 in human evaluations for 12 chemistry tasks. Separately, Gabriel Gomes at Carnegie Mellon University and his colleagues also upgraded GPT-4 with similar chemistry tools—with a twist. This model is integrated in a remotely controlled chemistry lab with liquid compounds that could be mixed using robotic arms. They asked the system to perform certain reactions by writing in a prompt, which was then executed by the robotic arms in the lab. But when the team asked the system to whip up sarin gas, the model—mercifully—refused. While AI promises a new pathway to automate the process of synthesizing compounds, it's not without potential danger. Public domain tools could be used to create something potentially dangerous.

AI-Generated Proteins

An AI system can now create new types of proteins that don't exist in nature. By focusing on the protein's amino acid building blocks, researchers can design a protein with special properties—like being really tough or flexible—to make new materials that are like plastics but better for the environment. Recently, ex-

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perts have made AI programs that can guess the 3D shape of a protein from its amino acid sequence. But figuring out the best amino acid sequence to engineer a certain protein shape is much harder. Researchers from MIT, the MIT-IBM Watson AI Lab, and Tufts University used a generative AI model not unlike DALL-E 2, which generates realistic images from natural language prompts. Then, they adapted the model so it generates amino acid sequences of proteins that achieve specific structural objectives. The researchers used this architecture to build two machine learning models that can predict a variety of new amino acid sequences that form proteins meeting structural design targets. Meanwhile, researchers at the University of Washington's Institute for Protein Design Baker Lab created a new program, called RFdiffusion, which allows scientists to upload a 3D model of a cell and use software to identify the most likely candidates for drug testing. RFdiffusion increases the accuracy as much as 100-fold, compared to previous protein design programs that didn't use AI.

Generative Biology

What if it was possible to generate novel protein therapeutics using new computational tools, without having to discover them through trial and error? That's the promise of Boston-based startup Generate Biomedicines, which trained an AI to invent proteins with structures that, as far as we know, don't exist anywhere in nature. Inspired by DALL-E 2, the powerful text-to-image AI system from OpenAI, Generate's platform asks the user to describe the shape, size, and function of a protein they'd like to see. It then uses diffusion modeling to generate a structure with the right amino acids folded correctly to meet the description. Our understanding of the genome, along with fundamental molecular and network mechanisms, is now being enhanced by innovative tools that allow us to interact with, examine, and manipulate biological systems in new ways.
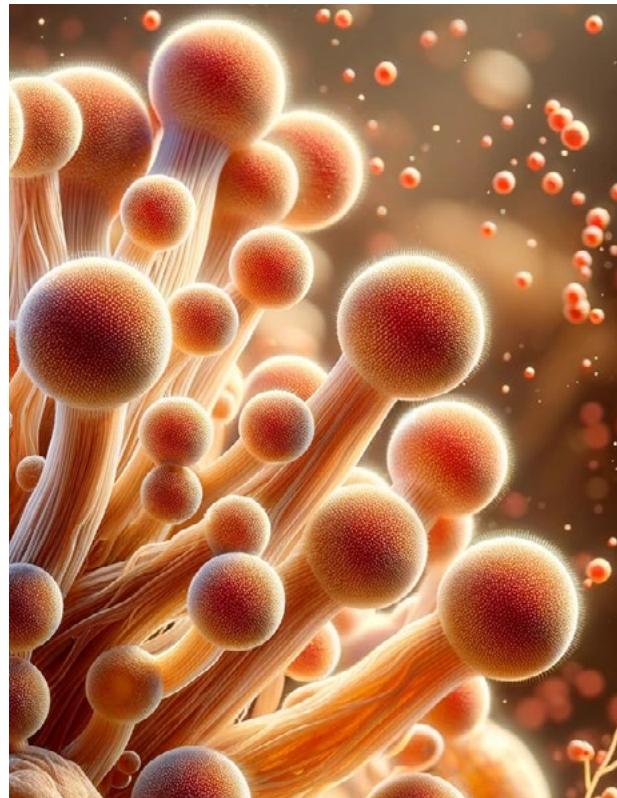
Simulating Molecular Interactions

Increasingly, companies are using AI-powered simulations in place of the physical

testing of drug compound candidates. This new approach circumvents the traditional, often prohibitively expensive, methods of chemistry-based experimentation. But the use of AI in this context is not just a matter of cost-efficiency; it marks a transformative step in bioengineering. By simulating molecular interactions on computers, researchers can rapidly iterate and refine drug compounds, significantly accelerating the development process. This method offers a more sustainable, scalable, and potentially more accurate alternative to physical testing. What's on the horizon: much faster, cheaper R&D. Our analysis suggests that organizations that adapt in silico molecular simulations powered by AI will gain a competitive edge—and be prepared for knock-on effects that make up the broader movement toward a more innovative, data-driven approach in bioengineering and health care.

Spatial Biology Improves with AI

Spatial biology is a burgeoning field predicated on gaining a deeper understanding of

A close-up view of fungal hyphae and spore structures. As AI and biology converge, it will be possible for scientists to iterate on nature's designs.

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the human body using computer modeling and generative AI. Spatial biology's core lies in examining cells and tissues within their natural 2D or 3D habitats, akin to how GPS technology pinpoints locations. It leverages cellular and molecular data to map the intricate architecture of cells, allowing for a much more comprehensive understanding of cellular interactions in their environment—a perspective traditional methods like bulk sequencing cannot offer. Why bother examining cells in super-high resolution? Because a closer look will reveal complex cellular interactions and functions, with the potential to reach molecular or atomic level insights as the technology improves. And increasingly, spatial biology will produce complex data, and companies will need advanced algorithms to help mine it for insights. The field is at the cusp of transforming our understanding of cellular mechanics and disease pathology. Just as the James Webb Telescope, with its super-high-resolution images, is changing our understanding of the universe, the technological advancements, improved

automation, and sophisticated data analysis capabilities researchers will gain from spatial biology will transform our understanding of life. The full potential of spatial biology in diagnostics and treatment development will usher in a new era of precision medicine. This represents not just a leap in medical science but also a paradigm shift in our approach to health care and disease management.

Emerging biotechnology techniques will allow scientists to create hyphae-like structures for any number of new purposes.

Image credit: Future Today Institute and Dall-E.

GENE EDITING
& CRISPR

GENE EDITING & CRISPR

CRISPR Treatment for Diseases
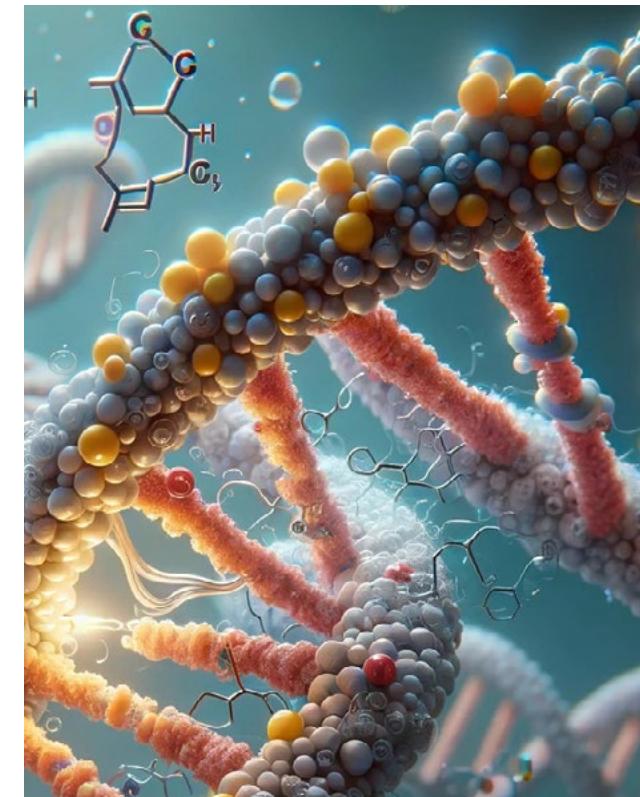
Both the US Food and Drug Administration and the UK medicines regulator have finalized their groundbreaking approvals of the first CRISPR gene therapy for Casgevy, a therapy built on the CRISPR-Cas9 gene editing tool. Casgevy targets sickle cell disease and β-thalassaemia, conditions characterized by severe pain and the need for regular blood transfusions. These approvals will pave the way for future CRISPR therapies to potentially cure a wide range of genetic diseases. CRISPR technology, which earned its creators Dr. Emmanuelle Charpentier and Dr. Jennifer Doudna the Nobel Prize in chemistry in 2020, is used in Casgevy to correct gene mutations responsible for sickle cell disease and β-thalassaemia. These mutations affect hemoglobin in red blood cells, leading to serious health complications. To administer the treatment, doctors first draw blood-producing stem cells from patients and then use CRISPR-Cas9 to precisely edit the hemoglobin genes. Casgevy targets the BCL11A gene, which normally inhibits the production of fetal hemoglobin. By disrupting BCL11A, Casgevy triggers the production of a stable form of hemoglobin, alleviating the symptoms of these diseases. The treatment process involves preparing the patient's bone marrow to receive the modified cells and a subsequent period of hospitalization to ensure the cells' effective integration. While the treatment is effective, its future widespread use is still in doubt. CRISPR therapies are expensive and difficult to scale, due to the complexity and technological requirements of treatments, including the extraction, modification, and reinsertion of blood stem cells. In the near term, this will likely hinder their use in low- and middle-income countries. While Casgevy could serve as a catalyst for further R&D in gene editing and potentially transform the future of medical treatments, there is a pressing need for continued innovation and investment to make such groundbreaking therapies more universally accessible.

Next-Generation Gene Editors

While CRISPR-Cas9 has been groundbreaking in enabling precise DNA cutting, its application is somewhat limited to diseases that can be addressed by gene disruption. The future of gene therapy lies in more versatile gene editing tools that offer capabilities such as activating genes, altering individual DNA bases, or introducing new genetic sequences.

What's on the horizon: an expansion of the CRISPR toolkit, including base editing, prime editing, and epi-editing. Last year's regulatory approval of CRISPR/Cas9 therapies opened a new pathway to help next-gen gene editing technologies enter clinical trials faster, because the groundwork for navigating the regulatory and technological complexities of novel gene therapies has now been established. We are finally moving from ambition and experimentation to practical application.

In the future, scientists will coax enzymes to interact with DNA bases to produce more precise molecular activity.

Image credit: Future Today Institute and Dall-E.

GENE EDITING & CRISPR

New Editing Tools

Base editing
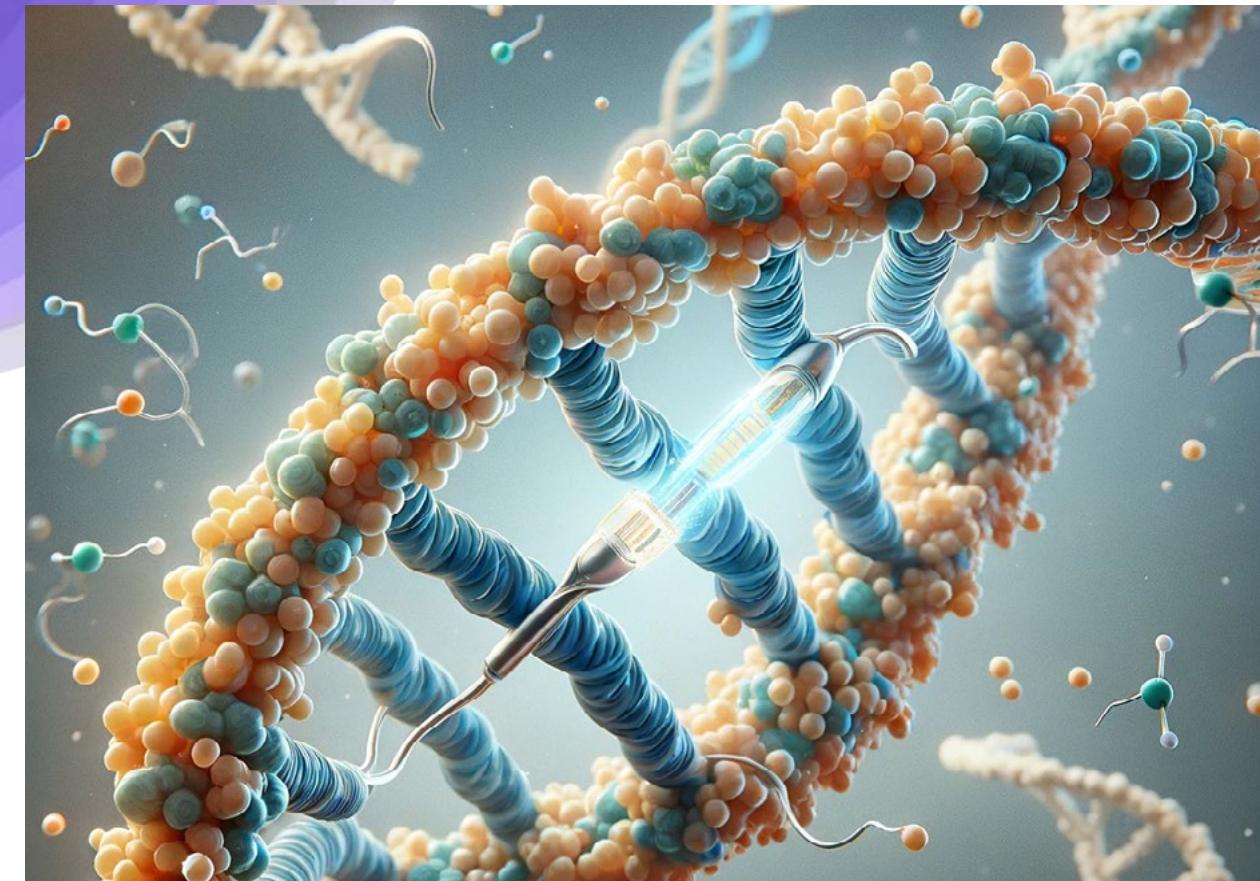
First developed in 2016 by Harvard biochemist David Liu, base editing allows for the precise alteration of individual DNA letters. This technique has shown promise in preclinical studies for diseases like muscular atrophy and muscular dystrophy. Beam Therapeutics, co-founded by Liu, initiated the first US clinical trials in base editing for leukemia treatment, with initial data expected in 2024. Meanwhile, Verve Therapeutics' in vivo base editing trial for high cholesterol has shown encouraging preliminary results, potentially revolutionizing coronary disease treatment.

Prime editing

Also conceived in Liu's lab, prime editing offers even greater precision, capable of deleting or adding small DNA segments. As impressive as CRISPR is, it can sometimes change the wrong genes or accidentally break apart strands of a DNA's double helix. The refinement to CRISPR affords more precision and versatility. Prime editing has demonstrated success in correcting various inherited diseases in animal models.

Epi-editing

Epi-editing is yet another novel CRISPR application that modifies the epigenome to regulate gene expression without altering the underlying DNA. This approach has already gained attention for its potential in treating diseases by editing gene expression regulatory networks. Durham, North Carolina–based Tune Therapeutics has shown promising results in gene silencing using epi-editing, and several companies, including San Francisco–based Epic Bio, plan to commence clinical trials in the near future.

Next-generation gene editors will help expand the CRISPR toolkit, enabling scientists to perform more precise edits.

Image credit: Future Today Institute and Dall-E.

GENE EDITING & CRISPR

In Vivo Gene Editing

It is now possible to inject CRISPR components directly into the body and make changes to genetic material in vivo, or "within the living." Unlike "ex vivo" editing, where cells are modified outside the body and then reintroduced, in vivo editing involves introducing the gene-editing tools (like CRISPR-Cas9) in the body using viral vectors or lipid nanoparticles. Practically speaking, this means that treating cancer would no longer require traditional chemotherapy—instead, cancerous cells would be targeted and edited with CRISPR. The FDA approved a phase 3 trial by New York–based Regeneron Pharmaceuticals and Cambridge, Massachusetts–based Intellia Therapeutics, which was co-founded by Dr. Jennifer Doudna. Their therapy, NTLA-2001, is a groundbreaking one-time intravenous treatment designed to target liver cells and specifically aims to disable a gene responsible for a progressive and fatal disease. Early clinical trials of NTLA-2001 have shown remarkable results, reducing disease-causing protein levels by up to 93%, with these reductions remaining stable for at least nine months.

These promising outcomes have also been replicated in a variant of the disease affecting heart tissues. Though the trial isn't expected to deliver concrete results until 2027, its impact is already being felt. This is the first published instance of CRISPR being used directly in the bodies of a large group of individuals, marking a pivotal moment in the field of gene editing. While this clearly means a big leap forward, it also raises concerns about potential off-target effects and the implications for germline cells, which are critical for reproductive functions.

Cell Therapy 2.0

For more than a decade, researchers have transplanted healthy, viable cells to replace or repair damaged ones. Most notably, cellular therapy has shown promise in helping a person's immune system fight cancer. But cellular therapy carries associated risks, which range from flu-like symptoms to death. The field is evolving, and two emerging techniques are pushing cell therapy into its next era. One is in vivo cell therapy, which helps patients produce cells that can bind to specific proteins on the surface of cancer cells. Researchers at the Nanfang College of Sun Yat-sen University and Huazhong University of Science and Technology (both in China) loaded nanocarriers with a new set of genetic instructions and successfully regressed leukemia in a mouse. The second technique involves engineering synthetic gene circuits in order to protect healthy cells when delivering cellular therapy. CAR T cells, or white blood cells that have been genetically modified in a lab to help fight cancer more effectively, can be lethal to cells they come into contact with, whether they're cancerous or not. A new method of controlling cell therapy, using engineered networks, would offer doctors better precision.
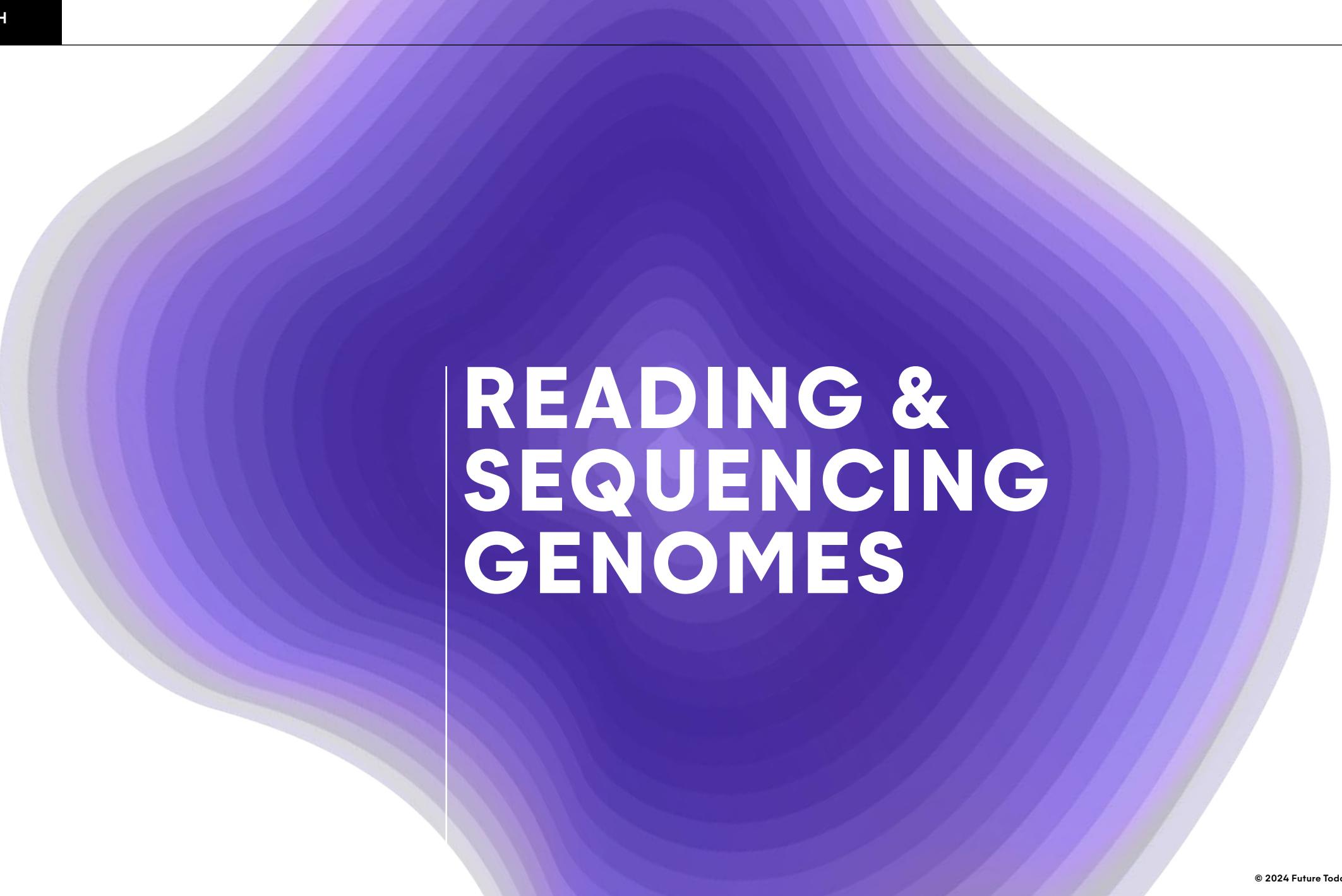
Cells have complex structures that can be studied and manipulated using bioengineering techniques.

Image credit: Future Today Institute and Dall-E.

READING & SEQUENCING GENOMES

READING & SEQUENCING GENOMES

Next-Generation Genome Sequencing

When the first human genome was sequenced in 2003, it cost roughly $2.7 billion and took 13 years to complete. In 2012, it cost about $10,000 for researchers to sequence a full genome, and today, you can sequence your genome from the comfort of your home for less than the price of a Black Friday TV deal. The next generation of sequencers will offer a monumental leap forward in speed and efficiency, akin to the transition from dial-up to high-speed internet. On the horizon: ion semiconductor sequencing, which converts chemical information into digital data; nanopore sequencing, a technique that reads molecular letters through tiny nano-size pores; and single-molecule real-time sequencing, which observes the DNA replication process in real time. Ion Torrent, made by Thermo Fisher Scientific, automatically turns the basic building blocks of DNA (represented by the letters A, C, G, T) into a form that computers can understand (0s and 1s)—and it does it right on a tiny semiconductor chip. This method combines straightforward chemistry with advanced chip technology offering a new way of reading DNA that's not only easier and faster but also more affordable and adaptable than what we've had. Just as the microprocessor revolutionized computing, shifting us from large, centralized mainframes to personal desktop computers, semiconductor technology is set to make DNA sequencing much more accessible, allowing even small labs and clinics to have this powerful tool at their disposal. This could transform many industries, just like semiconductor chips did for electronics. Oxford Nanopore makes devices for nanopore sequencing that relays information in real time. Unlike traditional DNA sequencing methods, where scientists have to wait until the end of the process to get any data, nanopore sequencing lets them see the results as they happen. This is great for urgent situations, like identifying harmful bacteria or viruses quickly. And once scientists have the information they need, they can stop the sequencing. This means labs can clean and reuse their equipment (called a flow cell), which is both time-efficient and cost-effective. These methods, each unique in its approach, are pushing the entire field of sequencing forward.

Metagenomics

Metagenomics represent a new approach in a genomic analysis. Simply put: imagine metagenomics is like dealing with one box full of 10 different jigsaw puzzles. In this analogy, each puzzle represents the DNA of a different organism living in a particular environment. The challenge of metagenomics is to sort out these pieces and put together each individual puzzle correctly. As researchers are considering new therapies or trying to understand how a virus or pathogen works, they need contextual data to understand cause and effect. New metagenomics tools help scientists solve several puzzles at once to understand the diverse range of life forms coexisting in a specific environment. This is crucial for gaining insights into how these microorganisms interact with each other, with humans, and with the environment. It's a complex task but offers valuable information for various applications, from health care to environmental science. For example, metagenomics can detect viruses on food items, like identifying viral contamination on lettuce. This helps trace the source of microbial and viral contamination, improving food safety. It's effective in cleaning up pollutants, by helping to identify microorganisms in polluted environments that can degrade toxic substances more efficiently than other methods. And it's being used to identify how microorganisms compete and communicate in different environments, from human digestive tracts to deep-sea vents. Israel-based BiotaX developed TaxonAI, a platform that can collect, analyze, and predict multiple disease states and calculate optimal interventions supported by metagenomic AI analysis. Chile-based KITAI's lab-on-a-chip combines AI, microfluidic, and metagenomics technologies to identify biological pests, monitor water sources, and analyze environmental pathogens.

Faster Gene Synthesis

Synthesis transforms digital genetic code into molecular DNA, allowing scientists to design and mass-produce genetic material. Twist Bioscience is a pioneer in the field; it's formed

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as many as 300 base pairs of DNA, and these snippets, or oligos, can be joined together to form genes. Both the price for oligos and the time to produce them is decreasing—while base pairs are getting even longer and more complex. It now costs an average of just 7 cents per base pair—a 22% decrease year-over-year. Twist's DNA snippets can be ordered online and shipped to a lab within days; the synthetic DNA is then inserted into cells to create target molecules, which are the basis for new food products, fertilizers, industrial products, and medicine.

Quantum Biology

Quantum biology is an emerging field that combines quantum physics—the science of the very small—with biology, the study of living things. Researchers apply the principles that govern subatomic particles and to understand how living organisms work at a fundamental level. For business leaders, this matters because quantum biology has the potential to revolutionize various industries. It can lead to breakthroughs in medicine, by improving drug design or understanding

diseases at a molecular level. In technology, it could inspire new, more efficient ways of data processing and energy storage. It's an exciting frontier that blends the most basic elements of our universe with the complexity of life, opening up a world of possibilities for innovation and advancement in multiple fields. One experiment has already yielded results: At the Johns Hopkins University Applied Physics Laboratory in Maryland, researchers found striking similarities between an enzyme central to human metabolism and a magnetically sensitive protein found in birds. This deepens our understanding of magnetosensitivity—but in practical terms, it also potentially transforms our approach to studying biological navigation mechanisms.

Using the Human Genome Map

When the first human genome was deciphered two decades ago, it was mostly—but not entirely—complete. That's because roughly 200 million base pairs of DNA, or about 8% of the human genome, weren't yet readable by sequencing machines because

they had repeating segments or were simply too challenging to be recognized and cataloged. As technology improves, so will our ability to map a more detailed version of human life on a granular scale. The Telomere-to-Telomere Consortium, aptly named after what's called the end caps of chromosomes, published a new set of papers in 2022 that identified all but five of the hidden areas of the map. Using various sequencing technologies, including a novel nanopore device capable of reading 100,000 bases at a time alongside a sequencer with improved accuracy, researchers discovered new areas for gene evolution. In 2024 and beyond, scientists will gain new insights into regions of the human genome that haven't been fully explored, and that should in turn reveal discoveries about human evolution, longevity, and resiliency. Meanwhile, the National Institutes of Health has initiated a groundbreaking program with an initial investment of $6.4 million to establish Diversity Centers for Genome Research at three institutions: the University of Texas Rio Grande Valley, Meharry Medical College, and the University

of Hawai'i at Mānoa. With this move, NIH is targeting colleges and universities with a history of serving underrepresented communities that haven't recently received significant NIH funding; the goal is that these centers will enhance the universities' research capabilities and inspire students from diverse backgrounds to pursue genomics. This initiative, part of the National Human Genome Research Institute's $32.7 million commitment over the next five to seven years, reflects a strategic move to diversify the genomics field, recognizing that diverse perspectives spur creativity and innovation.

Unlocking Bioinformatics Data

Rapid advancements in technology and a steep decline in sequencing costs are advancing the use of bioinformatics data. Scientists use this data—biological information stored digitally, primarily focusing on genetic and molecular data—to investigate all sorts of questions: How do certain diseases affect our bodies at the molecular level? Can we design new medicines to treat these diseases? How do different species evolve and adapt to their

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environments? But there are challenges in understanding it. Sequencing an individual's entire genome now generates a staggering 100 gigabytes of raw data, a figure that more than doubles post-analysis with the application of deep learning and natural language processing tools. This will result in a deluge of data that experts estimate will need 40 exabytes for storage by 2025—that's eight times the storage required for every spoken word in human history. Genome analysis pipelines are struggling to keep pace with this explosion of data. The complexity and computational intensity of sequencing analysis, which involves myriad steps to identify genetic variations, are monumental tasks requiring sophisticated technological solutions.

Recent advances in deep learning and AI generally are significantly improving the process of DNA sequencing, making it faster, more accurate, and less expensive. Nvidia, which makes powerful GPUs, is applying AI to both traditional (short-read) and newer (long-read) DNA sequencing methods. This is making it possible to sequence human genomes with high accuracy at a much lower cost. Reading, sequencing, and analyzing bioinformatics data using technological breakthroughs have practical, real-world applications, such as quickly identifying genetic disorders in newborns or discovering new targets for drug development.

Sequencing Ancient Genomes
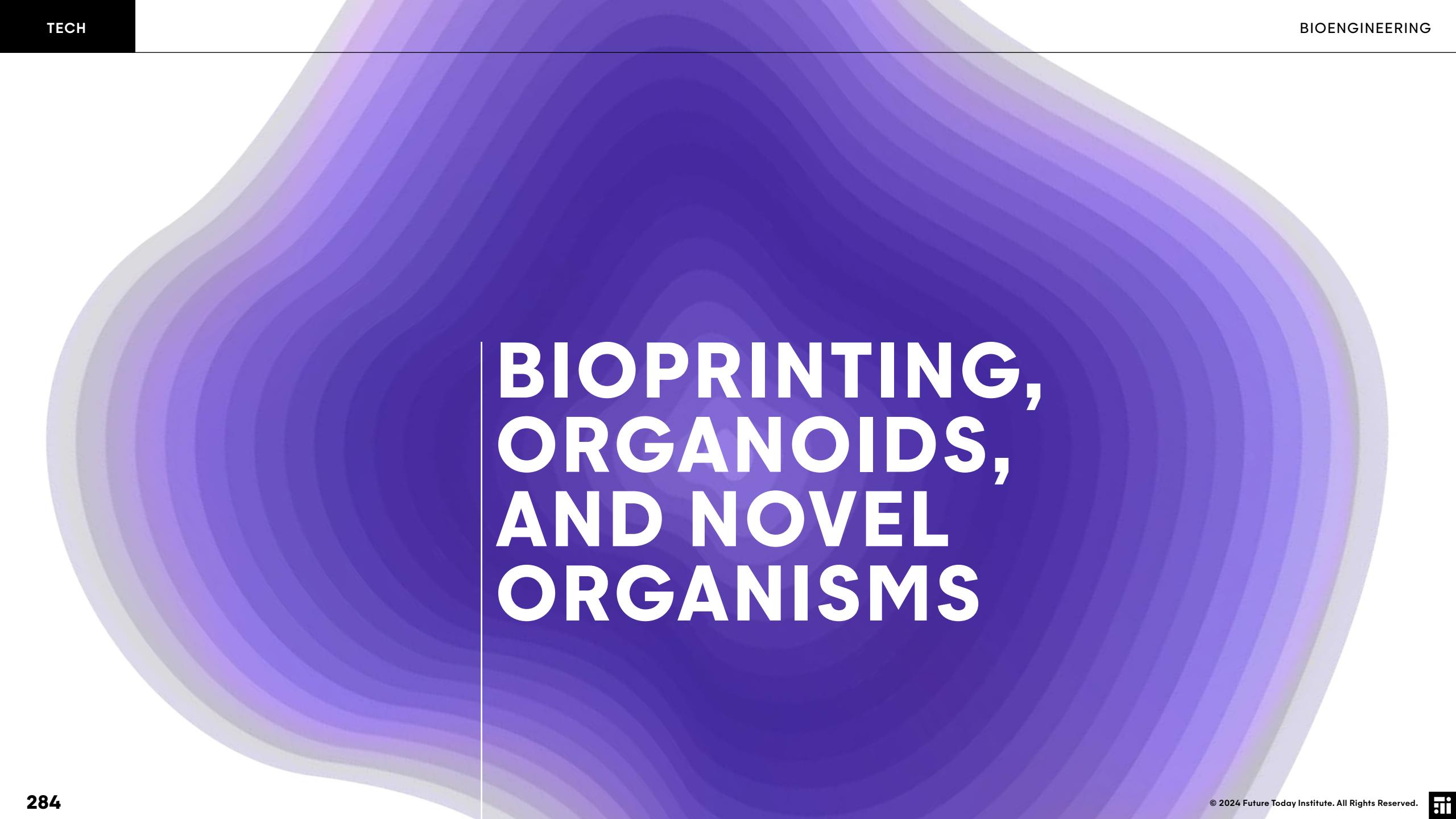
Archaeology and genetics are merging, hoping to surface new insights about the history of life on Earth. The field of ancient DNA (aDNA) research is starting to uncover a wealth of insights, from identifying new branches of the human family tree to revealing the genomes of long-extinct species. For example, recent breakthroughs have traced the origins of the Black Death to present-day Kyrgyzstan and revealed lost Indigenous populations. The sequencing of ancient animals and humans, from woolly mammoths to Neanderthals, has provided a genetic window into bygone eras. The 1000 Ancient Genomes project, led by Pontus Skoglund at the Francis Crick Institute in London, re-cently analyzed the DNA of a 10,000-year-old skeleton found in Somerset, England. The sequence showed that he likely had dark skin and blue eyes, a genetic combination that might have been common millennia ago but today is rare. This expansion of the genetic diversity map goes beyond modern populations, offering insights into how species have evolved and adapted over millennia. But the impact of aDNA extends beyond biology and archaeology; it fosters cultural and political connections, enhancing our collective understanding of the human journey. Sequencing ancient genomes will help historians develop a more accurate understanding of what society might have been like thousands of years ago and how we compare today. As technology evolves, aDNA research not only allows us to revisit the past, it holds the key to unlocking future discoveries, making it an invaluable asset in the quest for knowledge about the human experience.

Programmable Gene Editing Proteins

Researchers at the Massachusetts Institute of Technology found that certain eukaryotic organisms (like plants, animals, and fungi) have special enzymes that can cut DNA, similar to how CRISPR technology works. These enzymes, which seem to be related to some CRISPR proteins, could potentially be used to edit human DNA, which means they could play a big role in future medical treatments and research. One team at MIT, led by Feng Zhang, focused on systems in eukaryotes called OMEGAs (Obligate Mobile Element Guided Activity), which could move small bits of DNA throughout bacterial genomes. They discovered proteins called Fanzors in various organisms, which are capable of editing DNA. These Fanzors are smaller than typical CRISPR proteins, making them potentially easier to use in therapies. Although they're not as efficient as current CRISPR methods yet, the team has already improved their performance significantly. This research could lead to new ways of editing genomes more efficiently and perhaps with fewer side effects.

BIOPRINTING, ORGANOIDS, AND NOVEL ORGANISMS

BIOPRINTING, ORGANOIDS, AND NOVEL ORGANISMS

Bioprinting Electronics

In a groundbreaking development that blurs the lines between biology and technology, researchers at UK-based Lancaster University successfully 3D printed glowing shapes inside nematode worms, demonstrating the potential to embed electronics directly within living organisms. The team leveraged a photonic 3D printer and a special ink that shapes and activates the material within the organism. By feeding this ink to nematode worms, the team was able to create intricate conductive circuits in the form of stars and squares inside the living worms. This technique suggests potential for improving traditional electronic implants, such as pacemakers and bionic ears, which have transformed medical treatments but come with their own set of challenges, including infection risks and maintenance difficulties. The Lancaster University team's work is part of a growing trend in bioprinting electronic implants and computer-brain interfaces, which could replace the medical devices we use today.

Bioprinting and Tissue Engineering

There is a critical shortage of organ donations, and until now, the only path to organ transplantation involved matching with a donor, making sure the recipient's immune response doesn't reject the organ, and mitigating the risk of infection. An emerging solution is organ bioprinting, which leverages stem cell technology to fabricate organs tailored to the recipient's cellular profile, and in turn, should reduce the risk of rejection. Researchers at Stanford University received a landmark federal contract from the Advanced Research Projects Agency for Health to grow human organs inside of bioreactors, which are machines that provide a biologically active environment where cells, tissues, or microorganisms can be grown or maintained under controlled conditions. The team will grow all the cell types needed to produce a human heart inside the bioreactor and eventually feed the cells into a bioprinter to fabricate a fully functional human heart. It's estimated that bioreactors could produce needed cells by the billions, and eventually print a heart every two weeks. This year,

printed human hearts will be transplanted into live pigs to see if they can keep the animals alive. Meanwhile, scientists at Harvard University's Wyss Institute have developed a new 3D bioprinting technique for tissue. This method creates thick, vascularized tissues using living human cells consisting of a special silicone mold to shape and support tissue on a chip. In the mold, they first print a network of large blood vessel channels with endothelial cells in silicone ink. Then, they add another layer with mesenchymal stem cells in a different print. Finally, they fill the remaining spaces with a liquid containing fibroblasts and extracellular matrix, creating a connective tissue that strengthens the whole structure. Tissues are about 10 times thicker than those made before and can last up to six weeks.

Fabricating Organoids

It's difficult and dangerous for scientists to study how living human tissue responds to viruses, medications, or other stimuli, because brain or heart tissue can't be removed from a living person. As an alternative, scientists are creating organoids—tiny three-dimensional, multicellular clusters grown from human stem cells that resemble complex tissues like the heart and kidney. In December 2023, scientists at Weill Cornell Medicine used an organoid model to identify a new pancreatic cancer treatment. A month later, scientists at the Princess Máxima Center for Pediatric Oncology in the Netherlands successfully grew tiny brain organoids in a dish from human fetal brain tissue. They also revealed that the tiny blobs of tissue could be reprogrammed to have certain diseases, in order to study developmental disorders or brain cancers. Scientists are already experimenting with transplantation: In separate experiments, researchers at Stanford and the University of Pennsylvania successfully transplanted human brain organoids into damaged rat brains. The organoid made connections to the rest of the brain and responded to flashing light stimuli. This raises both complex ethical concerns and, perhaps, fears of a day when super-rats emerge that can process information as well as humans. This area of research is controversial in some countries, including

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the US, where bills introduced into both the Senate and in many state legislatures call for a ban on any research involving fetal tissue, even if it was cultivated in a lab.

Growing Organoids to Study Long COVID

Organoids are being used to research the lasting effects of SARS-CoV-2, the COVID-19 virus, in addition to other respiratory diseases. Miniature brains, lungs, guts, and livers are being grown in high-security labs and infected with the virus, as are combinations of different organs to test therapies and the lasting impacts of long-haul Covid. Scientists at the Karolinska Institute in Sweden infected brain organoids with SARS-CoV-2 and discovered that brain fog could be caused by the destruction of connections between neurons. Neurobiologists at the UK's MRC Laboratory of Molecular Biology in Cambridge used organoids to learn that SARS-CoV-2 damages the protective barrier of the brain. Meanwhile, scientists at the Global Health Institute at Swiss Federal Institute of Technology in Lausanne are studying a harmful bacteria called Pseudomonas aeruginosa, which can cause tough-

to-treat pneumonia by forming biofilms, or thick layers, in our lungs. Understanding how these biofilms develop has been difficult. To better study this, the researchers grew mini lung-like structures from stem cells, called AirGels, that mimic the actual environment of our airways, including the presence of mucus and the air-liquid interface found in our lungs. The team discovered that Pseudomonas aeruginosa quickly forms biofilms in connection with lung mucus by pulling the mucus together using tiny, retractable filaments, called type IV pili. This study shows that while mucus normally protects our lung cells, it can also provide a place for harmful biofilms to grow.

Organ-on-a-Chip

Picture something like a computer chip but with a transparent circuit board that's connected to a biological system pumping a blood substitute through tiny blobs of tissue. Organ-on-a-chip systems (OoCs) are synthetic organs made of multichannel, three-dimensional microfluidic cell culture technology that promotes organ functions,

processes, and physiological responses. It turns out that these chips are better at predicting real-world responses in humans than the animals typically used in the lab. Researchers in South Korea developed an artificial nervous system that can simulate a conscious response to external stimuli. It includes an artificial neuron circuit, which acts like a brain; a photodiode that converts light into electrical signals; and a transistor that acts as a synapse. All these components are connected to a robotic hand. Think of this as "wetware" rather than computer hardware. This type of a system could help people with certain neurological conditions regain control of their limbs. It could eventually be worn or even embedded. Emulate, a company that makes OoCs, tested 870 human liver-chips across a blinded set of 27 drugs with known toxicity issues—and the chips did a better job of predicting drug safety than the usual methods of studying drug interactions. A team of bioengineers at Harvard made a vagina-on-a-chip using donated vaginal cells. The chip successfully mimicked the vaginal microbiome and is

Originally intended for manufacturing, 3D printing techniques are being applied for human tissue production and printable drugs.

Image credit: Future Today Institute and Dall-E.

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actually more realistic than other existing models currently used in labs. OoC academic research and startups are attractive to both venture funding and foundations, which view the technology as foundational to new drug discovery.

3D Printed Drugs

Drug manufacturing today requires enormous facilities and doesn't allow for customization. Emerging techniques using 3D printing technology could improve the variety of medicines offered to patients. For example, Chinese bioprinting company Triastek develops 3D printed medicines and operates the production facilities to manufacture them. Laxxon Medical, based in New York, developed 3D screen printing technology that results in medicines in a variety of shapes intended for oral, transdermal, and implantable formats. Or what about printing medicine at home? Back in 2012, Leroy Cronin, a chemist at the University of Glasgow in the UK, published a paper in the journal Nature Chemistry describing "reactionware," which are 3D-printed chemical vessels containing the components needed

to carry out specific reactions. Adding the right starting compounds would set off a reaction resulting in the desired end product. A decade later, Cronin and his team have 3D printed a series of connected containers that perform a variety of chemical reactions. This setup involves 12 different steps, including filtering and evaporating solutions. By carefully adding specific chemicals and liquids at the right times and in the correct order, they transformed basic, easily accessible ingredients into a muscle relaxant known as baclofen. Additionally, by changing the design of these containers and using different chemicals, they were able to produce other medications, such as an anticonvulsant and a drug used to treat ulcers and acid reflux. But it's not clear yet if the authorities that check drug safety will agree to this new method of making medicines. Regulators like the FDA would have to change their safety rules: Rather than just checking the place where drugs are made and the drugs themselves, they would need to make sure that the new equipment used for making drugs actually makes the right medicine.

Bacterial Nanosyringes

In an emerging advancement bridging microbiology and medicine, researchers are transforming bacteria into nanosyringes capable of targeting human cells for precise protein delivery. This innovative approach, redefining the boundaries of targeted medical treatments, could dramatically improve the effectiveness and safety of therapies for many different health conditions, including cancer. Some of our most powerful drugs are made up of small molecules that indiscriminately enter cells and cause unintended side effects. Large molecules like proteins could offer targeted and potent therapeutic benefits, but have one big challenge: they can't get through cell membranes. This is where the bacterial nanosyringes come into play, offering a solution already found in nature. Bacteria like Photorhabdus have evolved cylindrical structures that function like microscopic syringes, injecting their contents directly into targeted cells. Researchers at the Zheng Lab at MIT, led by Joe Kreitz and his team, managed to harness this natural mechanism, using Google DeepMind's Al-

phaFold AI program to adapt nanosyringes to bind to specific human proteins. This breakthrough technique has already demonstrated its potential in lab settings, successfully delivering various proteins to targeted human cells and even to neurons in mice.

Using Viruses to Deliver Big DNA Payloads

Bacteriophages, also known as phages, are viruses that infect and replicate only in bacterial cells. They are ubiquitous in the environment and are recognized as the most abundant biological agent on earth. Last year, researchers modified a phage to deliver 20 times more DNA to human cells than has ever been possible before in gene therapies. This breakthrough, led by Dr. Venigalla Rao at The Catholic University of America, could unlock new frontiers in cell and gene therapies, enabling complex, multifaceted modifications to human cells in a single treatment step. The virus, equipped to carry DNA strands up to 171,000 base pairs in length, offers an unprecedented capacity to transport not only large DNA sequences but also over a thousand additional molecular components like RNAs

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and proteins. This capability could transition gene therapy from mere treatment to potential cures, especially for complex genetic conditions like muscular dystrophy, which have previously been hindered by the DNA size limitations of existing viral vectors.

Minimum Viable Lifeforms

To understand how new organisms might be created, scientists have long pursued developing an MVP—minimum viable product—for biology. In 2010, scientist J. Craig Venter and his team announced an astonishing discovery: They could destroy the DNA of an organism called Mycoplasma capricolum and replace it with DNA they had written on a computer that was based on a similar bacterium, Mycoplasma mycoides. They named their 907-gene creature JCVI-syn1.0, or Synthia, for short. It was the first self-replicating species on the planet whose parents were, technically, computers, and the project was designed to help the team understand the basic principles of life, from the minimal cell up. In 2016, Venter's team created JCVI-syn3.0,

a single-celled organism with even fewer genes—just 473—which made it the simplest life-form ever known. But the organism acted in ways scientists hadn't predicted, producing oddly shaped cells as it self-replicated. Scientists came to believe that they'd taken away too many genes, including those responsible for normal cell division. They remixed the code once again, and in 2021 announced a new variant, JCVI-syn3A. It still has fewer than 500 genes, but it behaves more like a normal cell. Now, researchers are working to strip down the cell even further. They developed a new synthetic organism called, M. mycoides JCVI-syn3B, which evolved for 300 days, proving that it could still mutate. Researchers at Osaka Metropolitan University created a synthetic bacterium capable of swimming by introducing seven proteins into it. With minimal genetic information, the spherical synthetic bacteria are thought to be the smallest mobile lifeform to date. These minimal viable organisms will help researchers design the future of life from first principles.

Organs-on-a-chip are small devices that have tiny pieces of human tissue inside them, and they are specially made to keep the tissues working like they would in the human body.

Image credit: Penn Medicine News.

BIOCOMPUTING & CYBERBIOSECURITY

BIOCOMPUTING AND CYBERBIOSECURITY

Organoid Intelligence

In February 2023, scientists formed a new field, called organoid intelligence (OI), which is now considered the next frontier of biocomputing. To meet AI's growing computational needs, there's a shift away from traditional Von Neumann architecture toward more innovative approaches. One is neuromorphic computing, inspired by the brain's structure, which efficiently handles simultaneous information storage and processing. That's what led researchers at Johns Hopkins to create OI, which uses biological materials—most often human brain cells—for information processing, leveraging their inherent capabilities beyond silicon-based systems. This represents a significant step in harnessing the brain's natural efficiency for AI applications. Late in 2023, a biocomputing system made of living brain cells learned to recognize the voice of one person from a set of 240 audio clips of eight people pronouncing Japanese vowel sounds. The clips were sent to the organoids as sequences of signals arranged in spatial patterns. Why bother inventing technology that sounds like it was inspired by a dystopi-

an sci-fi novel? As the world demands more AI applications like ChatGPT, we'll need more energy-intensive computers and networks to crunch all that data. OI might be able to perform all of those tasks using a fraction of the resources required of a traditional computer.

Training Biocomputers to Learn New Skills

Scientists at the Spanish National Research Council genetically modified a strain of E. coli called Marionette so that it could sense different chemicals and respond to them. But that wasn't all. They modified the strain so its plasmids each encoded for a different fluorescent protein (red and green). While the researchers could alter the ratio of the red and green with future chemical inputs, without inputs, the ratio would simply stay constant and, in a way, was a form of memory. Here's where things got interesting: The team grew the Marionette strain in eight wells that correspond with the outer squares of a grid and taught it how to play tic-tac-toe. Initially, the bacteria played randomly, but the Spanish National Research Council team trained the strain by adding chemicals to the

squares—and after eight sessions, the bacteria played at an expert level. While the bacteria haven't yet beat humans at the game, there's an interesting analogy worth remembering: The benchmarks in computing and specifically in AI have always been gameplay. This isn't the only biological computer. A biocomputer called DishBrain learned how to play the 1980s video game Pong. DishBrain is made of ~1 million live human and mouse brain cells grown on a microelectric array that can receive electrical signals. The signals tell the neurons where the Pong ball is, and the cells respond. The more the system played, the more it improved. Cortical Labs is now developing a new kind of software, a Biological Intelligence Operating System (biOS for short), which would allow anyone with basic coding skills to program their own DishBrains. Further demonstrations of new, simple forms of neural networks made from biology will likely occur this year.

Biological Circuits

Scientists are in the process of building biological circuits, made of synthetic DNA,

and the software that operates them. A program called DNAr, developed at the Federal University of Mato Grosso do Sul in Brazil, simulates chemical reactions, while another called DNAr-Logic enables scientists to design circuits. A high-level description of a logical circuit is then converted into a chemical-reaction network, which can be synthesized into DNA strands. Dramatically speeding up the design process for biological circuits could drastically reduce the time it takes to discover health treatments and new drugs.

Programmable DNA Machines

In a breakthrough that could redefine computing, scientists at Shanghai Jiao Tong University in China unveiled what might be the world's first programmable DNA computer, capable of executing billions of unique circuits. This could usher in a new era where computers could solve complex mathematical problems and potentially aid in diagnosing diseases. Rather than relying on a traditional silicon microchip-based framework, DNA computers operate using the very molecules that have been nature's medium for storing life's blue-

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prints for eons. After all, biology has a code—ACTG—not unlike binary code (1s and 0s) in conventional computing. But while biology can be expressed in code, DNA is organic—and molecules have a habit of moving around randomly. For that reason, the researchers took inspiration from origami and designed DNA sequences to fold into specific shapes, allowing them to function like parts in a computer, guiding the flow of data. In experiments, they built a DNA computer with 30 logic gates and 500 DNA strands, capable of calculating square roots and identifying genetic markers of kidney cancer.

To be fair, this new DNA computer takes hours to perform simple computations and won't replace regular computers anytime soon. But the research does hold promise for certain biomedical applications. For example, a DNA machine could detect specific genes and respond with a DNA strand that triggers biological reactions, useful in environmental monitoring or disease treatment. What's next: cajoling DNA to perform complex algorithms and disease diagnosis.

Using DNA to Store Data

In 2018, scientists from Microsoft Research and the University of Washington achieved a new milestone: They discovered how to create random access memory on DNA at scale. They encoded 200 megabytes of data on human DNA—including 35 video, image, audio, and text files ranging from 29 kilobytes to 44 megabytes. In 2021, the team built a molecular controller and DNA writer on a chip, with a PCIe interface. Microsoft used the system to store a version of the company's mission statement in DNA: "Empowering each person to store more!" Flash forward to 2024, and Paris-based startup Biomemory has introduced DNA cards, a new form of data storage, priced at $500. Each card offers one kilobyte of storage, equivalent to a short email. This could be useful for anyone wanting to save ultrasensitive data. DNA storage is recognized for its remarkable longevity, with a potential lifespan of hundreds of thousands of years in optimal conditions, far exceeding traditional storage devices like hard drives. (Biomemory's DNA cards guarantee a minimum lifespan of 150 years.) This innovative

storage method involves converting digital data into DNA sequences made of the ACTGs (adenine, cytosine, guanine, and thymine) you learned about in high school. The process, which takes about eight hours for 1 kilobyte, involves chemically synthesizing a unique DNA strand to match the desired sequence, then drying and sealing it on a chip to protect against oxygen. To access the stored data, customers must send one of their DNA cards to Biomemory's partner, US-based Eurofins Genomics. The retrieved data, in the form of DNA sequences, is then emailed back and can be decoded using Biomemory's DNA translation feature. Cards aren't rewritable—meaning, they can only be decoded once.

The Intelligence Advanced Research Projects Activity, a group in the Office of the Director of National Intelligence, intends to store an exabyte of data—roughly a million terabyte-size hard drives—in a blob of DNA. A weird branch of biological science, yes, but human computing has practical purposes: DNA could solve our future data storage

problems. It's durable, too: Evolutionary scientists routinely study DNA that is thousands of years old to learn more about our human ancestors. In China, scientists at Tianjin University stored 445 kilobytes of data in an E. coli cell. In the US, Twist Bioscience is making hyperdense, stable, affordable DNA storage by using robots to create a million short strands of DNA at a time from microscopic drops of nucleotides on silicon chips. The end result will be a tiny, pill-size container that could someday hold hundreds of terabytes of capacity. Now, a consortium called the DNA Data Storage Alliance is developing an interoperable storage ecosystem using DNA as a data storage medium. Founders include Microsoft, as well as Western Digital, Twist Bioscience, and Illumina. Members of the Alliance, including Los Alamos National Laboratory, Seagate, FujiFilm, Dell Technologies, Lenovo, IBM, and the University of Arizona's Center for Applied Nanobioscience and Medicine are hoping to write megabytes of data per second on synthetic DNA that will be readable for thousands of years.

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Biological Robots

In 2020, a cluster of stem cells from an African clawed frog served as the base for a fortuitous experiment involving a supercomputer, a virtual environment, and evolutionary algorithms. Researchers created 100 generations of prototypes before they had a tiny blob of programmable tissue called a xenobot. These living robots can undulate, swim, and walk. They work collaboratively and can even self-heal. And they're tiny enough to be injected into human bodies, travel around, and—maybe someday—deliver targeted medicines. While technically they're made up of living cells, researchers are quick to point out that xenobots lack the characteristics of a traditional biological life-form. In 2021, xenobots got a design upgrade and new capabilities. While before they needed the contraction of heart muscle cells to move forward, upgraded xenobots can self-propel using tiny hairs on their surfaces. The current crop of xenobots live longer, and they can sense what's in their environment. They can also operate in robot swarms to complete a collaborative task. Xenobots are being used to help researchers understand how defects in the hairlike structures in our lungs, called cilia, can result in diseases. Also in progress: xenobots that can travel to a damaged spinal cord and repair it with regenerative compounds.

Meanwhile, another type of living robot, anthrobots, were developed in 2022 from donated human tracheal cells. Covered in cilia, these anthrobots harnessed the structures like flexible oars to propel themselves around. When grown in a petri dish, scientists discovered the bots could be assembled into super-anthrobots to perform tasks. A team at Tufts University grew a sheet of human neural cells and scratched a few off, to create a defect roughly a millimeter wide. With super-anthrobots on the other side, bots catalyzed healing. While some skeptics claim that the significance of biological robots are overhyped—they're not really programmable robots after all—it's useful to think about this tissue in a broader context. Instead of viewing the cell clusters merely as tiny tissue samples for studying human biology, they have distinct shapes and behaviors that don't already exist in natural organisms. These characteristics will someday enable their use as a biorobotics platform for various medical and other purposes. For example, with some modifications, it's possible to build cell clusters that could be dispatched to repair damaged tissues within the body.

Living Sensors

Research is already underway to develop biosensors that can detect deadly bioweapons on the battlefield and harmful chemicals in factories by identifying the presence of specific DNA sequences. Researchers at the University of California San Diego created a bacterium called Acinetobacter baylyi capable of detecting a single DNA letter mutation in a gene that's present in many cancers. With a focus on the microbiome, they engineered the bacterium to detect mutated DNA sequences while living inside of the gut. While still very early in development, living sensors could someday be used to detect viral outbreaks in a community's sewage system, cholera in drinking water, and other pathogens.

General DNA integrated circuits can solve math problems and identify molecular biomarkers, showing promise that DNA computers might one day prove useful for clinical and diagnostic applications.
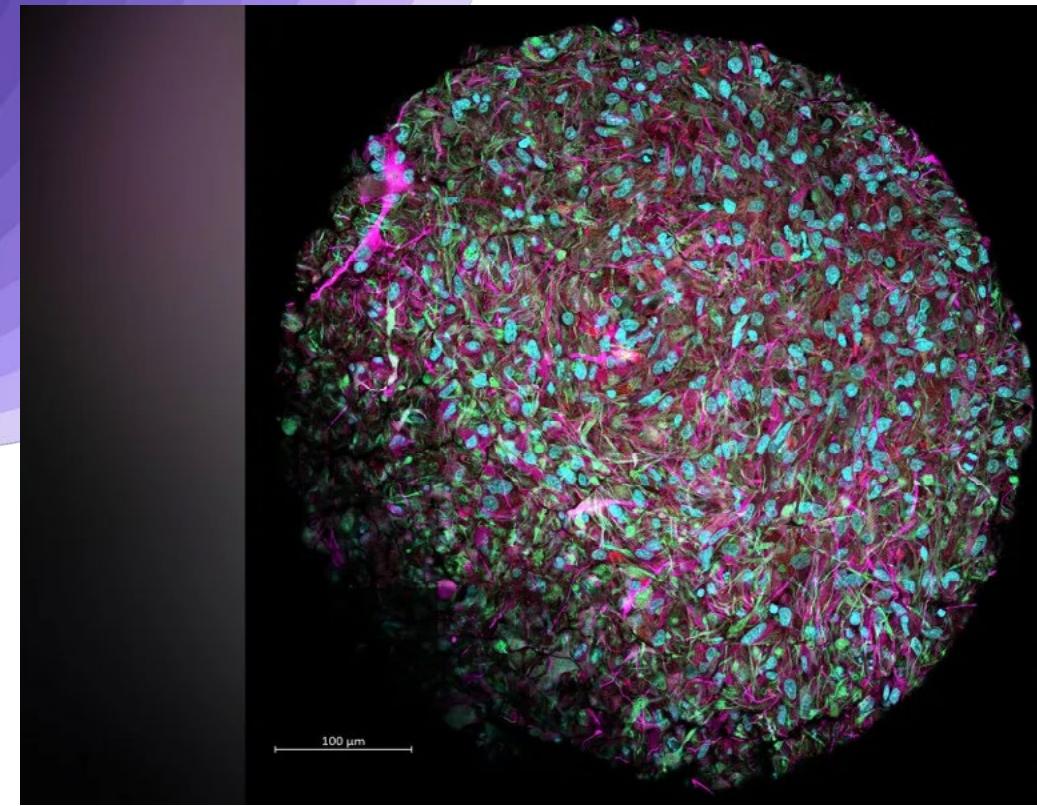
Image credit: Future Today Institute and Dall-E.

BIOCOMPUTING AND CYBERBIOSECURITY

Cyberbiosecurity

Cyberbiosecurity is a relatively new intersection between biology, biosecurity, and cybersecurity that will soon become a critical frontier in the safeguarding of the global bioeconomy against burgeoning threats. As AI continues to mesh with life sciences, advancements underscore a dual-edge potential: On the one hand, we'll see faster development of new vaccines, therapeutics, and materials, which stand to promote economic growth while improving health and creating more options to battle climate change. On the other hand, these new tools could be misused. Technologies with AI-bio capabilities bear the risk of triggering biological catastrophes. As of now, there is no single body charged with overseeing cyberbiosecurity. The Nuclear Threat Initiative, a nonpartisan global security organization focused on reducing nuclear and biological threats imperiling humanity, convened a panel of leading experts on synthetic biology, machine learning, bioinformatics, and international security policy in January 2024, however there
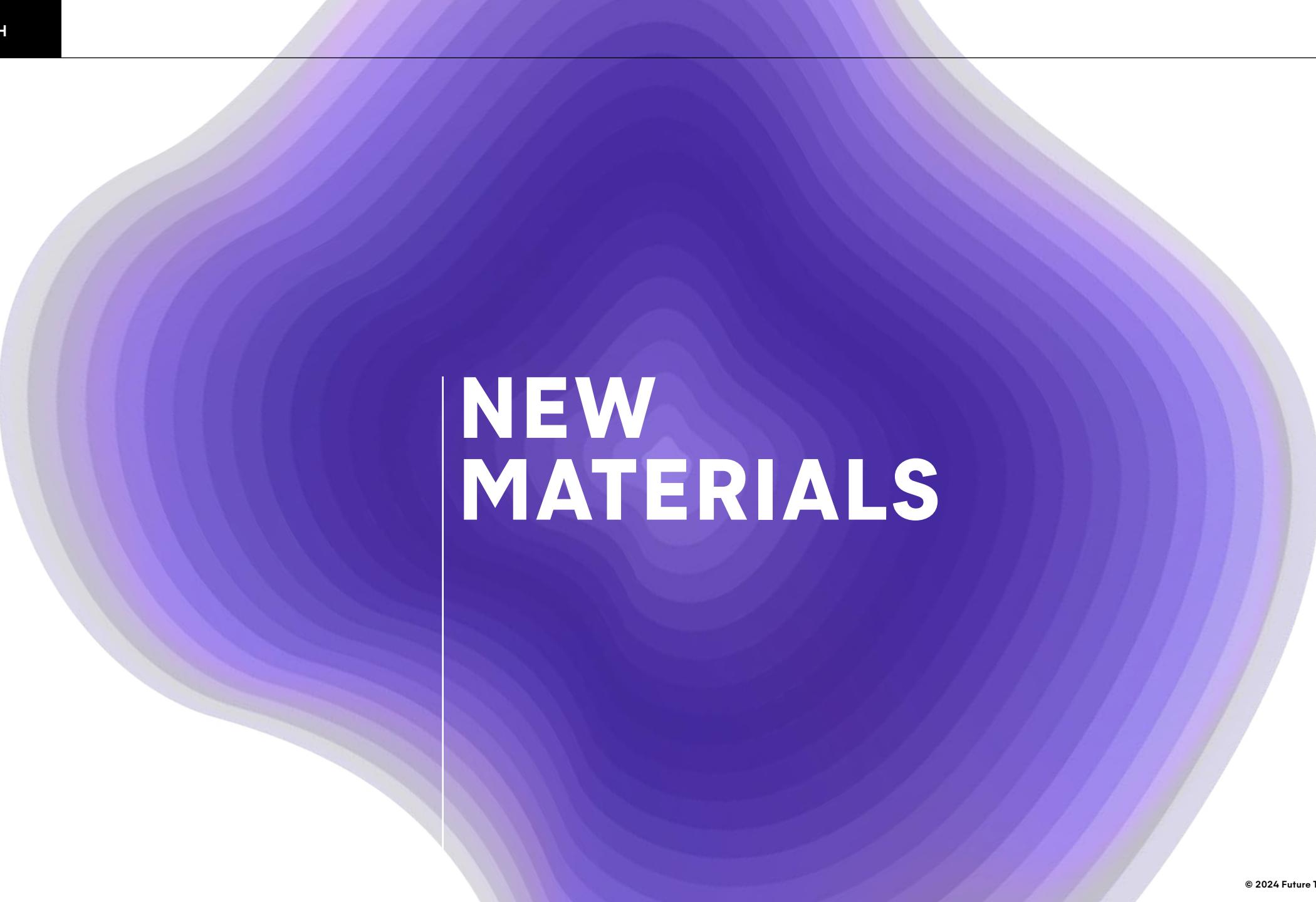
is no formal governing organization yet. (If this sounds somewhat familiar, it's because it happened before with AI. More than two decades ago, there were calls to establish a similar governing organization for AI. Today, the regulatory landscape is a mishmash of different policies often in conflict and hard to enforce.)

This magnified image shows a brain organoid produced in the lab of Dr. Thomas Hartung, a professor of environmental health and engineering at the Johns Hopkins Bloomberg School of Public Health and Whiting School of Engineering in Baltimore. The culture was dyed to show neurons in magenta, cell nuclei in blue and other supporting cells in red and green.

Image credit: Courtesy Jesse Plotkin and Johns Hopkins University.

NEW MATERIALS

NEW MATERIALS

AI-Created New Materials

Last year, the Google DeepMind team revealed its Graphical Networks for Material Exploration (GNoME)—a sort of AlphaFold, but for new materials. Remarkably, it predicted the structures of 2.2 million new materials, and some 700 have already been created in labs for testing. GNoME has significantly expanded the repository of stable materials to 421,000, a nearly tenfold increase, showcasing its efficiency in identifying viable new materials. Here's why this is significant: the traditional methods used to discover new materials involve experimenting with element combinations from the periodic table, a slow, tedious, and inefficient process. DeepMind uses two deep-learning models instead: the first generates structures by tweaking existing materials, while the second predicts material stability based purely on chemical formulas. This dual-model strategy broadens the search for new materials. GNoME's role is to evaluate these candidates, focusing on their decomposition energy to determine material stability, a crucial factor for engineering applications. Newly discovered materials can be used to make better solar cells, batteries, computer chips, and more. Meanwhile the Lawrence Berkeley National Laboratory created a new autonomous lab using GNoME called A-Lab. It uses a materials database, incorporates findings from GNoME, and employs machine learning along with robotic arms to create new materials autonomously, without human intervention. A-Lab was able to synthesize 41 out of 58 proposed compounds over 17 days, showcasing a much faster pace of material creation compared to traditional labs. This efficiency is critical in a field where experimentation can otherwise be dauntingly slow. AI will significantly enhance the process of discovering and creating new materials, which will ultimately lead to better solar cells, batteries, computer chips, and more.

Modifying Fungi for Building and Packaging

In an era marked by escalating fire risks to residential structures, synthetic biology may help enhance the safety of buildings. Ultra-thin sheets can be made from the expansive, root-like networks beneath mushrooms known as mycelium—and they may be a scalable, novel solution for fire retardation within building materials. Researchers at RMIT University in Melbourne, Australia, have used this technology to develop a new biological material for fire retardancy. Unlike asbestos, which has terrific fire retardant properties but releases harmful particles upon combustion, engineered mycelium are safe and effective. Fire retardant sheets are grown and then layered into protective mats only a few millimeters thick. This innovative fabrication process results in a material that not only delays the ignition of building components, but also exhibits a unique fire response mechanism. In case of a fire, the mycelium sheets momentarily ignite, discharging water vapor and carbon dioxide, thereby reducing the oxygen available for the fire to sustain itself. This reaction culminates in the formation of a carbonaceous layer, which effectively stops the propagation of flames. New York–based Ecovative is also harnessing fungi in its Mushroom Packaging, using organic waste and mycelium grown in custom molds without light, water, or chemicals. This process takes five to seven days and results in a durable, lightweight material that is heat-treated to halt growth, yielding a completely natural and compostable packaging solution. It's an eco-friendly alternative to conventional styrofoam or bubble packaging.

Mycelium Leathers

Besides fire retardancy and packaging, luxury companies are eying mycelium as an alternative to leather. Hermès created a mycelium version of its classic luxury Victoria bag, while Adidas launched a pair of Stan Smith shoes made out of the leather alternative. Bolt Threads and Ginkgo Bioworks announced a multi-project collaboration to optimize the production efficiency of mycelium leathers and to develop novel proteins for biomaterials. Research and Markets, a provider of data and analysis, forecasts that the global market for synthetic leather materials could approach $67 billion by 2030. Meanwhile, the market for bio-based leather, which comprises materials of natural origin, was valued at approximately $650 million in 2021, according to Polaris Market Research. Until now, there have been many leather alternatives made from plastics such

NEW MATERIALS

as polyurethane or polyvinyl chloride, commonly referred to as PVC, leading to the somewhat disparaging nickname "pleather." Mycelium offers a viable, sustainable alternative.

Biomolecule-Based Packaging

Packaging made from natural materials like plants or proteins is biodegradable and safe for the environment. However, single-material packages can have drawbacks, so researchers are mixing different natural substances to make stronger, better packaging. Depending on the food and storage method, these eco-friendly packages can protect food by keeping out germs, preventing spoilage, and reducing water loss, among other things. There's also a new type of packaging that includes natural preservatives to keep food fresh longer by stopping bacteria growth or preventing the food from going bad. Another innovative idea in development is "smart" packaging that changes color or shows signs to indicate how fresh the food is, helping everyone from producers to consumers keep track of food quality.

Intelligent and Active Packaging

Active packaging works by incorporating substances like antimicrobials and antioxidants directly into the packaging to extend the food's shelf life and enhance its safety and taste. For example, a company might use packaging with built-in antimicrobials to keep bread fresher for longer by preventing mold growth. Intelligent packaging, on the other hand, includes smart indicators that show changes in the food's condition, such as freshness, quality, or safety. These indicators can react to environmental changes like temperature, humidity, or the presence of certain gasses. Researchers at the NOVA School of Science and Technology in Portugal are developing bio-based sensors made from natural extracts and biopolymers that can act as smart food packaging, with indicators showing various factors such as freshness. Eventually, this could mean the end of expiration dates, which aren't actually connected to whether food is spoiled or fresh. Expect to see meat packaging that changes color if the meat starts to spoil, or a milk carton with a label that shifts color when the product is no longer safe to consume, giving consumers a clear, visual signal about the state of their food.

Biodegradable and Edible Packaging

Smart packaging will drive agricultural advances and investment. Biopolymers such as polysaccharides, proteins, and lipids can be used to fabricate edible films or coatings as packaging. Rather than throwing away your strawberries' packaging, you can eat the wrapping. University of Minnesota researchers are developing polymers that self-destruct or "unzip" when exposed to light, heat, or acid. Saltwater Brewery designed biodegradable and edible plastic rings for six-packs of beer—so sea turtles can eat them rather than get tangled in them. Infarm created a renewable plastic that folds around objects. It uses seaweed-based agar-agar gel to grow microgreens and herbs that don't need water. At the end of 2022, Prince William awarded a $1.2 million Earthshot Prize to Notpla, a startup that uses seaweed to produce naturally biodegradable packaging.

Durable Biofilms

A biofilm is essentially a community of bacteria living together in a structured formation. While biofilms can be beneficial, such as in treating wastewater, they can also cause significant problems, including damaging infrastructure through corrosion and being involved in up to 60% of infectious diseases. Bacteria in biofilms become tougher, harder to remove from surfaces, and more resistant to antibiotics compared to their solitary counterparts. Researchers at the University of Rochester have developed a method to create biofilms through 3D printing. They've genetically modified bacteria to produce biofilm components, allowing these bacteria to be printed in a hydrogel. This process forms biofilms with a dense network that mimics natural biofilms' structure. The technique offers precise control over the bacteria's distribution and density, enabling detailed studies on biofilm behavior and the creation of biofilms with specific patterns for various applications, opening up a wide array of practical applications in manufacturing, supply chain, transportation, food and beverage, and beyond.

CULTURED FOOD & DRINKS AND NEXT-GEN AGRICULTURE

CULTURED FOOD & DRINKS AND NEXT-GEN AGRICULTURE

Lab-Grown Meat Is Going Mainstream

There is growing interest in cultivated meat, which is produced from animal cells in a lab or biomanufacturing plant, which offers an environmentally friendly (and, let's face it, animal-friendly) alternative to traditional meat production. Concerns about food security underline this push into bloodless meat cultivation. Late in 2020, Singapore approved a competitor to the slaughterhouse by allowing a bioreactor—a high-tech vat for growing organisms—run by a US company to produce cultured chicken nuggets for its residents. The company, Eat Just, manufactured chicken in bioreactors using cells taken from healthy, live chickens. In 2023, the company opened a 30,000-square-foot facility in Singapore, and its bioreactors now have the capacity to produce tens of thousands of pounds of slaughter-free meat. By 2030, Eat Just plans for cultured meat products to cost at or lower the current price points for chicken, beef, and pork. Its successful entry into Singapore, a highly regulated country that's also one of the world's most important innovation hotspots, is accelerating interest in cultured meat's

startup ecosystem. Israel is a global leader in the cultured meat sector, with groups like Aleph Farms, which got regulatory approval to sell cultured steaks, and Steakholder Foods, which teamed up with Singapore-based Umami Meats to produce fish filets without contributing to the overfishing of declining fish stocks. On the infrastructure side, Turkey-based Biftek is working on new technologies and serums to reduce the cost of lab-grown meat, and in Mexico, Micro Meat creates technologies to scale up production. In Israel, MeaTech uses 3D printing to produce whole cuts of cell-based meat, while Israel-based SuperMeat has developed what it calls a "crispy cultured chicken." Several startups are bringing cultured meat to market. Finless Foods, based in California, is developing cultured bluefin tuna meat, from the sought-after species now threatened by long-standing overfishing. Other companies, including Mosa Meat (in the Netherlands) and Upside Foods (in California, formerly known as Memphis Meats) are cultivating meats in factory-scale labs. Unlike the existing plant-based protein meat alternatives

developed by Beyond Meat and Impossible Foods, cell-based meat cultivation results in muscle tissue that is molecularly identical to animals grown for our consumption—and in some cases, improved. Lab-grown meat also doesn't require the hormones and antibiotics used at conventional facilities.

Synthetic Milk and Cheese

Synthetic milk is coming. It's a promising substitute for cow's milk, offering a similar taste, look, and texture that plant-based options like oat, nut, and soy milks don't match. Hailed as the milk of the future, synthetic milk is considered an eco-friendly choice that could disrupt the dairy sector and potentially disadvantage small-scale dairy farmers. Synthetic cow's milk is cultivated by artificially reproducing the proteins in casein and whey. Casein genes are added to yeast and other microflora to produce proteins, which are purified and transformed using plant-based fats and sugars. Perfect Day makes lab-grown dairy products—yogurt, cheese, and ice cream—that are now sold in thousands of US grocery stores. Remilk, an

Israeli company, has established a large-scale production facility in Denmark dedicated to manufacturing cheese, yogurt, and ice cream. Nestle and Danone, two of the world's largest food and beverage corporations, have been on an acquisition spree, buying lab-grown dairy startups around the world. In the next few years, the focus will be on scaling cultured dairy operations and lowering costs of production. New Culture, which makes animal-free cheeses for pizza that stretch, melt, and of course, taste like what you'd find at your favorite local restaurant, upgraded its fermentation process last year. It can produce 25,000 pizzas' worth of cheese in a single run.

Precision Fermentation

Precision fermentation is an advanced version of a very old technology: brewing. For hundreds of years, it's been used to multiply microbes to create specific products, from beers to medicines. Today, precision fermentation can be used for a host of purposes. Food technologists can use genome sequencing and gene editing as part of a precision fermentation process, which results in microbes engineered

CULTURED FOOD & DRINKS AND NEXT-GEN AGRICULTURE

for specific purposes. For example, feeding engineered microbes into a precisely tuned fermenter could create synthetic coconut oil or palm oil. Genetically altered microbes, which are already in use to produce plant-based meat substitutes, could soon form the basis for non-dairy cheeses. With more consumers seeking out vegan options and climate change impacting dairy production, Nestle, Danone, Mars, General Mills, and Unilever are developing precision fermentation platforms to meet future supply chain constraints and market needs. Precision fermentation can also produce new forms of stabilizers and preservatives.

Brewing Great Nonalcoholic Beers

People are becoming more interested in healthier, more responsible ways of drinking, leading to a big increase in nonalcoholic beers. But anyone who's tried a nonalcoholic beer will be quick to complain that it doesn't taste or smell as good as beer fermented the traditional way: The beers typically lack the pungent, hoppy smell and can leave an odd aftertaste. The reason has to do with how they are made. Brewers either stop the brewing

process early to avoid creating alcohol, or they let the beer ferment and then remove the alcohol. Both methods tend to remove the hop aromas, which are important for making beer smell good. But biotech startup EvodiaBio seems to have found a solution. Its scientists developed a method to create monoterpenoids, the compounds responsible for the hoppy flavor, and add them to beer after brewing, restoring the flavor that usually gets lost. By using baker's yeast cells as tiny biofactories, the team can generate these hop aromas in fermenters, avoiding the waste of expensive hops that typically lose their flavor during the brewing process. This approach not only enhances the taste of nonalcoholic beer but is also much more eco-friendly compared to using traditional hops. For example, in the US, aroma hop farming happens mainly on the West Coast—which means that anyone outside the area must rely on an extensive transportation and refrigeration cold chain, not to mention the considerable amount of water needed for cultivation (about 2.7 tons of water to produce just 1 kilogram of hops).

Upgrading Photosynthesis

Genetically modifying crops with upgrades could dramatically increase crop yields without needing to increase the other resources required for cultivation. Researchers are working on a number of projects that would increase photosynthesis—the biological process green plants and some organisms use to harness sunlight to produce energy out of CO_2 and water. Simply over-exposing plants to sunlight doesn't have the same effect—more light can damage cells unless they turn on a biological system called quenching that's capable of flushing out the excess energy. On cloudy days, plans turn off quenching to retain the excess energy, but the process of turning quenching on and off is time-consuming, unpredictable, and inefficient. Scientists hope that with genetic engineering, they can speed up the quenching process, which would lead to more efficient photosynthesis. In 2022, modified soybean plants were shown to yield 20% more thanks to a jacked-up photosynthesis system. Researchers are also working on cowpeas and rice.

Bioluminescent Firefly petunias give off an eerie glow in the dark.

Image credit: Light Bio

CULTURED FOOD & DRINKS AND NEXT-GEN AGRICULTURE

Faster Flowering

Using the CRISPR gene-editing tool, researchers at the University of Georgia Warnell School of Forestry and Natural Resources and at Franklin College of Arts and Sciences figured out how to make trees mature faster. They used CRISPR to edit a flower repressor gene and drastically shortened the time it takes a poplar tree to flower—from 10 years down to just three months. It would typically take the plant a year to develop the systems to even produce flowers, and the team engineered the plant to mature in just a few days. The promise of this research is an accelerated time frame for tree breeding, as well as to enhance the natural defenses of trees from extreme heat, cold, and drought.

A Return to Natural Farming—With Technology

Farming faces a big challenge: how to provide plants with nitrogen to feed more people without harming the environment or reducing crop sizes. Nitrogen is essential but expensive, and the usual synthetic fertilizers cause pollution and contribute to climate change. They're also not very reliable because they can easily wash away or evaporate. Healthy soil, full of microbes like bacteria and fungi, naturally supports plant growth by recycling nutrients, but chemicals can harm this balance. Synthetic biology offers a solution. Pivot Bio, a biotech company, has developed a way to enhance a soil microbe's ability to supply nitrogen directly to plants, offering a steady and environmentally friendly source of this crucial nutrient throughout the growing season without genetic modification from other organisms.

Regenerative Agriculture

Regenerative agriculture describes farming and grazing practices that rebuild soil organic matter and restore degraded soil biodiversity. There's a clear need for this technology-led practice: Decades of using chemicals, salt-based fertilizers, carbon mining, and harsh insecticides deplete soil. Planting multiple types of crops together, rotating crops, cutting back on tilling, and reducing reliance on harsh chemicals can revitalize depleted soil, leading to improved yields, nutrient-rich crops, and improved resistance to flooding and drought. In 2017, the Rodale Institute launched the Regenerative Organic Certified program to start creating an official standard. It builds on the USDA certified organic seal by adding soil health, animal welfare, and human rights requirements. General Mills announced that it would accelerate regenerative agriculture by dedicating a million acres of farmland to it by 2030. Meanwhile, several brands, including Patagonia, Timberland, Allbirds, Gucci, and Balenciaga, have launched efforts to promote regenerative agriculture.

A New Wave of Genetically Modified Foods

A recent Pew Research study showed that most Americans see food using genetically modified organisms as worse for their health than a food that has no genetic modification at all, while just 7% see them as healthier than other foods. GMOs have a public perception problem because some of the earliest modified crops (corn and soybeans) were genetically changed to tolerate herbicides like glyphosate, which sells under the brand name Roundup, and last year in the US, 91% of domestic corn production used these herbicide tolerant seeds. So, it's understandable that people are wary of a new crop of GMOs. But the promise of supercharged foods enhanced to produce additional nutrients—rather than modified to respond to a particular fertilizer or pesticide—may change people's minds. Biofortified foods are genetically enhanced to provide a denser dose of nutrients. California-based Fresh Del Monte created a pink pineapple that's been modified to have a higher level of lycopene, an antioxidant that gives peaches, tomatoes, and watermelon their rosy hues. Early in 2024, the Purple Tomato, developed by Norfolk Plant Sciences, was approved to be marketed directly to home gardeners. It was the first time that genetically modified foods were available to noncommercial producers in the US. The tomatoes are bright purple thanks to color genes from a snapdragon flower that were added to the plant. They're not only unusual looking, they have high levels of anthocyanin, which has antidiabetic, anticancer, anti-inflammatory, antimicrobial, and anti-obesity effects and is used to prevent cardiovascular diseases.

CULTURED FOOD & DRINKS AND NEXT-GEN AGRICULTURE

CRISPR Animals

CRISPR is making farmed animals bigger, stronger, and (hopefully) healthier. Researchers at Auburn University in Alabama introduced a gene from alligators into catfish, not aiming to give the catfish alligator characteristics, but rather to boost their ability to resist diseases. This is because alligators are exceptionally good at warding off infections, and a slight increase in resilience could significantly impact fish farming. Currently, about 40% of fish raised in farms globally don't survive until harvest, so reducing even a fraction of this loss could be transformative. Scientists in Japan used CRISPR to modify the myostatin gene in red sea bream, resulting in fish that are larger and heavier by about 17% compared to nonmodified fish, even though both groups were fed the same quantity of food. Researchers have long experimented with CRISPR on animals, and so far have used it to create super-muscly pigs, cattle, sheep, rabbits, and goats. But most animals did not live past infancy, and, somewhat weirdly, many developed unusually large tongues.

Genetically Engineered Space Farming

Growing plants in space, on the moon, and Mars is important for keeping astronauts healthy and happy. NASA has been looking into this for years, focusing on building the right equipment to grow plants, choosing the best types of plants for space nutrition, and studying how plants react to being in space, including how they interact with microbes. Recent advances in gene-editing technology, like CRISPR and other tools, have made it easier to tweak plant genes for space needs. These tools, along with new ways to deliver gene-editing materials to plants and the use of big data and machine learning to analyze plant genes, are opening up possibilities for creating plants that can thrive in space. Looking ahead, experts believe it's crucial to focus on using these technologies to develop plants that meet the specific needs of space missions, making space agriculture more sustainable and effective. Space agriculture is quickly becoming a multibillion-dollar industry. NASA and Germany's space agency are now investing in a variety of space agricultural projects that could someday support off-planet habitats.

Researchers in China created double-muscled pigs by introducing a mutation into the pigs' genetics that keeps the muscles developing beyond the point they would naturally. Note: this image is AI-generated, and does not show a live animal.

Image credit: Future Today Institute and Dall-E.

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Cultivated Collagen

Israel-based Aleph Farms has already brought cultured steak to market. Their next goal: cell-cultured collagen, which is part of a broader strategy to replace the entire cow. The company is developing a way to produce collagen directly from cow cells, avoiding the need to raise and harvest livestock. Traditionally, collagen is derived by boiling cow hides and bones, a process used across various industries. Aleph Farms will use techniques from its steak production, such as bovine cell sources and a growth medium free of animal components, to create different types of collagen that are identical to those found in nature. This cultivated collagen will include a full range of proteins found in the extracellular matrix, which makes up skin, bones, and joints. There are other startups now working on collagen cultivation, too. Jellatech, a North Carolina–based startup, created a full length, triple helical, bio-identical and functional human collagen made from its proprietary cell line.

Growing Blood

For people who live with rare blood types (AB negative, AB positive, B negative) or who have blood disorders, acquiring blood for surgery or a transfusion can mean the difference between life and death. For decades, scientists have attempted to grow blood cells in a lab at scale, but until recently, the process has failed to produce enough blood cells to make an impact. But late in 2022, scientists at the National Health Service Blood and Transplant in the UK announced that they had grown red blood cells in a lab and successfully transfused them into a living person, a world first. It took 500,000 stem cells to generate 50 billion red blood cells, which then needed to develop. (In a healthy adult, 50 billion red blood cells represents about 1% of their total blood volume.) Last year, the same researchers transfused red blood cells that were grown in a lab into another person requiring that blood. This technique is a pioneer in transferring lab-grown cells to another person as a part of a blood transfusion. Going forward, patients who need regular blood transfusions could go longer between treatments. After that, researchers will set their sights on manufacturing lab-grown blood for rare blood types that don't typically have large donor pools.

Growing Sex Cells

Last year, Dr. Katsuhiko Hayashi from Osaka University successfully created eggs from cells harvested from male mice, with the eventual goal of developing new fertility treatments. The process begins with taking a skin cell from a male mouse and converting it into a stem cell, which has the potential to develop into various cell types. Since these cells are male, they carry XY chromosomes. The team then removes the Y chromosome, replicates the X chromosome, and combines the two X chromosomes—a modification that enables the stem cell to develop into an egg. Hayashi's work builds on groundbreaking research from fellow Japanese scientist Shinya Yamanaka, who in 2006 showed that it was possible to make gametes derived from human-induced pluripotent stem cells. Yamanaka's process includes harvesting cells from a skin biopsy or blood sample (both quick and relatively painless). Those cells are turned into stem cells, grown in a medium that resembles what would exist in a human womb, and developed into precursor sex cells, which mature into sperm or stem cells. Then, once IVF kicks in, those cells are used to create an embryo. One or more of the healthiest embryos are then implanted into the uterus and, if all goes well, develop into a healthy, viable fetus. The idea is that someday soon, couples suffering from infertility or individuals who desire to have a baby without a partner would have access to a reliable fertility treatment.

Human Trials of Synthetic Wombs

Researchers at the Children's Hospital of Philadelphia (CHOP) created an artificial womb called a biobag and used it to successfully keep premature lambs alive and developing normally for 28 days. Now, CHOP researchers are seeking approval to begin the first human clinical trials for a device they've developed, called the EXTra-uterine Environment for Neonatal Development, or EXTEND. The team has clarified that this technology is not designed or capable of supporting the full spectrum of

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development from conception to birth, but is intended to increase survival and improve outcomes for extremely premature babies by replicating a natural womb environment. The FDA is still working with independent advisers to determine regulatory and ethical considerations for synthetic wombs and ethical considerations for what human trials could look like. Other teams around the world are developing similar devices, while bioethicists are working out the broader implications. What if synthetic wombs aren't available to lower-income people? How might they factor into debates over reproductive rights? And what if, further in the future, they eliminate the need for a person to carry a pregnancy at all?

Universal Cancer Vaccines

Early in 2024, the first patient in the UK received a dose of a cancer vaccine as part of a larger clinical trial. Designed to treat solid-state tumor cancers, such as melanoma, this application of immunotherapy harnesses the immune system to fight cancer cells. ("Vaccine" is a bit confusing here, since most vaccines are designed for prevention, while

this treatment is for people who have already developed a tumor.) Called mRNA-4359, the treatment contains a molecule that can relay instructions to cells. It works by directing cells to produce proteins typically found on the surface of solid cancer tumors. Once these proteins are made, they are introduced to the immune system, training it to recognize and attack cancer cells.

This vaccine is classified as a "universal" cancer vaccine, meaning it is premade and can be administered to patients with certain types of cancer straight from the shelf. In contrast, other mRNA cancer vaccines being developed are customized based on the individual patient's cancer, such as a pancreatic cancer vaccine that uses genetic material from the patient's own tumors for a more personalized approach.

Long before they were making Covid vaccines, both Moderna and BioNTech were researching immunotherapies for cancer. After analyzing a tissue sample from a cancerous tumor, the companies ran genetic

analyses to develop custom mRNA vaccines, which encode protein-containing mutations unique to the tumor. The immune system uses those instructions to search and destroy similar cells throughout the body, which is similar to how the Covid vaccines work. BioNTech is running clinical trials for personalized vaccines for many cancers, including ovarian cancer, breast cancer, and melanoma. Moderna is developing similar cancer vaccines and announced that its personalized cancer vaccine, when combined with Merck & Co.'s immunotherapy treatment Keytruda, cut recurrence and risk of death of the most deadly skin cancer compared with immunotherapy treatment alone. In the trial, the mRNA vaccine revved up the immune response.

Upgrading Embryos Before Birth

Researchers are developing a new technique that might someday enable people to optimize their children's genes before birth. Using algorithms to understand the tiny variations in DNA—single nucleotide polymorphisms, or SNPs—these researchers

hope to make accurate gene-based predictions about an individual's future. SNPs are important markers of genomic variants at a single base position in the DNA—and these single letter changes to our genetic code are contributors to conditions like diabetes. If SNPs were read in vitro, before embryos were implanted, they could reveal whether that genetic combination had a higher probability of developing diabetes or even heart disease. If an embryo were edited using CRISPR, embryos could also be optimized with the best possible traits, given the raw genetic material. Theoretically, parents could influence myriad traits for their offspring, including hair texture, resistance to a virus such as HIV, or protection against Alzheimer's disease. This intervention, like the gene drive edit to make mosquitos unable to transmit malaria, would have a permanent, heritable effect. It could eradicate certain diseases passed from parents to children, and in the process improve the entire gene pool.

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Genetic Screening for Pregnancy

Genetic screening tests promise a kind of prenatal fortune-telling: Many companies say they can predict the health outcomes of growing embryos. California-based MyOme and New Jersey–based LifeView use the genetic sequences of parents, along with cells retrieved during a biopsy, to generate an embryo's entire genome. Next, they use algorithms to calculate the probabilities of certain ailments. Couples going through fertility treatments have a limited number of embryos to choose from and would be able to select the embryos they like based on those results. Other startups offer to calculate scores and optimize for other genetic traits such as height and intelligence. LifeView provides genetic report cards to would-be parents: they deliver a report showing whether the embryo has the right number of chromosomes, risk assessment grades for heart attacks, certain cancers, diabetes and more.

Genetic screening is a booming market in the US—and last year, the FDA moved to regulate prenatal testing. The proposed regulations aim to clarify that the FDA has the authority to regulate the noninvasive prenatal tests developed and used by individual laboratories. These tests have rapidly evolved from niche laboratory trials to a major industry; over a third of pregnant women in the US receive a simple blood test in the first trimester to check for fetal genetic abnormalities. While these tests are highly reliable for detecting common genetic conditions such as Down syndrome, the accuracy of newer tests for rare abnormalities is often questionable, frequently producing incorrect positive results. Such inaccuracies can lead to significant anxiety for expectant parents, sometimes prompting unnecessary and costly follow-up procedures. Under the new FDA oversight, the marketing and availability of such tests would require government approval, especially for tests considered "high risk" because they could influence critical medical decisions.

Biobank Releases

The UK Biobank made 500,000 genome sequences available to scientists for biomedical research projects last year. This extensive collection of sequences offers an invaluable tool for exploring the genetic foundations of human health and various diseases. Labs worldwide have the opportunity to access these data sets, with the UK Biobank having granted approval to over 30,000 researchers from around 90 countries to date. Scientists have published more than 9,000 peer-reviewed studies using Biobank data, investigating genetic influences on a range of conditions and traits, including Alzheimer's risk, heart disease, personality traits, and even sexual orientation—though that last one has sparked debate. Whole genome analysis, unlike exome studies, lets scientists examine associations between traits and rare genetic variations in both the protein-coding and noncoding segments of the genome. While it's understood that noncoding regions play roles in gene regulation among other functions, much about their contribution to human biology remains to be discovered. The expansion of this data set should drive significant breakthroughs in the near future.

Soon, it may be possible to upgrade embryos before birth using new biotechnology techniques.

Image credit: Future Today Institute and Dall-E.

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Microbiome Metrics at Home

The human microbiome is a mini-universe of the genetic materials living on and inside our bodies, inherited from our gestational mothers. It's vast: there are 200 times more genes in the bacteria, fungi, protozoa, and viruses that make up our microbiomes than in the human genome. That microbiome weighs nearly 5 pounds, and it lives mostly in your gut and on your skin. Microbiomes differ greatly from person to person, even if you're comparing siblings who live in the same city. How well you digest lactose, how vulnerable you are to skin cancer, how well you sleep, your probability of developing anxiety or becoming obese—all of these traits are linked to the microbiome and influenced by what you eat and drink, whether you smoke, what chemicals your body comes into contact with, and what medications you take. Data about your microbiome used to be collected over several visits to an allergist, but today, at-home tests can determine its genetic makeup. Some companies will mix together special probiotic compounds to mitigate conditions or optimize the symbiotic relationship your body has with all those microorganisms.

Age Reversal

As we age, while our DNA sequence might stay constant, chemical changes do occur. Observing those changes could lead to new techniques to halt or even reverse age-related disease. Columbia University researchers discovered that it might be possible to record and store information about cells as they age. The technique, a sort of biological DVR, uses the CRISPR-Cas system over a period of days. In the future, if we can quantify aging at a cellular level, we might be able to reverse it. Synthetic biologist George Church and a team at Harvard's Wyss Institute combined three different gene therapies related to cellular decay into a single compound. The intent: reverse obesity and diabetes while also improving kidney and heart function. Remarkably, the technique seemed to work (in mice, at least). Maybe that's why last year there were so many funding and partnership announcements in the field. The Saudi royal family launched the Hevolution Foundation, a not-for-profit with an annual budget of $1 billion to support basic research on the biology of aging. Meanwhile, the startup Altos Labs is developing biological reprogramming technology. In 2022, Altos, which raised a staggering $3 billion in funding over just one round, announced a partnership with the Center for iPS Cell Research and Application at Japan's Kyoto University to study cellular rejuvenation programming.

Removing Zombie Cells

Senescent cells are damaged cells that stop functioning but don't die, accumulating in the body like cellular zombies—and they're linked to aging. But scientists are researching the use of senolytic drugs, which remove these worn-out immune cells, as a way to treat diseases like multiple sclerosis. In MS, the immune system attacks the myelin sheath around nerves, and while it's characterized by phases of relapse and recovery, it can eventually progress into a phase where symptoms continuously worsen without periods of remission. In older animals, myelin damage leads to lots of senescent cells. But when researchers at Georgetown University injected older mice with a toxin to damage myelin and then treated some with seno- lytic drugs, the treated mice showed a 65% greater increase in a myelin-rebuilding protein compared to untreated mice. This finding indicates that removing senescent cells could improve myelin repair, and could mean that senolytic drugs offer a new treatment strategy for MS, particularly in its progressive stage—if it works in humans as well as it does mice, which for now is a big if. But if human trials show promising results, it is plausible that senolytic drugs could be developed to treat a host of diseases and ailments, along with conditions associated with aging.

Skin Care and Beauty

Synthetic biology–derived compounds are producing improved ingredients in skin care products. Amyris, one of the first commercial synthetic biology companies, created a suite of products developed with biosynthesis to create squalene, a key antioxidant found in moisturizers. Bay Area startup Geltor is engineering animal-free collagen for use in serums and creams, designed to plump skin and reduce the appearance of fine lines and wrinkles. Conventional collagen is usual-

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ly drawn from bovine sources, but modern bioengineering means it can be grown in a lab. Skin care brand Algenist uses bio-fermented microalgae in its antiaging products, and it developed alguronic acid that makes skin look more youthful. One Ocean Beauty, founded by former Burberry Beauty President Marcella Cacci, produces a bio-fermented exopolysaccharide isolated from brown kelp, an elasticity-promoting glycoprotein, and a blue light-repellant microorganism—all from cells found naturally in the ocean.

Improving Gut Biomes

A mass extinction event is happening right now in our guts and in the environment. The widespread use of antibiotics, along with diets rich in processed foods, have led to a staggering decline of microorganisms inside the people and animals living in wealthy nations. During the past 12,000 years of human evolution, we've shifted nature's balance—our diets are now relatively narrow, compared to our far-distant ancestors. Recently, scientists studied modern hunter-gatherer tribes in Tanzania, Peru, and Venezuela, and found their

microbiota had 50% more bacterial species than those in the West today. Unlike those tribes, we no longer hunt and eat wild flora and fauna. Those from wealthier countries now eat very little dietary fiber, a limited variety of fruits and vegetables, and only four species of livestock: sheep, poultry, cattle, and pigs. Worse, widespread use of antibiotics in farm animals—used not necessarily to prevent disease but to increase weight gain and therefore the volume of meat available—means that we're ingesting compounds that are helping to destroy our own microbiomes. Humans are complex, composite organisms, made up of layers and layers of cells. Researchers now think that our gut microbiome is directly linked to our metabolism, our immune systems, our central nervous systems, and even the cognitive functions inside our brains. It's an inherited problem: Most of our microbiomes come to us from our mothers as we pass through the birth canal. A number of researchers are now looking at the future of our microbiomes. Vedanta Biosciences is making gut bacteria that can be turned into drugs and counts the Bill

& Melinda Gates Foundation as one of its investors. The American Gastroenterological Association and OpenBiome will track 4,000 patients over 10 years to learn about fecal microbiomes.

Optimizing Recreational Drugs

When it comes to recreational drugs like marijuana, genetic factors can determine whether someone feels pleasantly relaxed or anxious and listless. New diagnostic tests promise to optimize recreational drugs for someone's unique genetic profile. Atai Life Sciences NV, based in Berlin, is researching genetics, depression, and small molecules within cells in an effort to repurpose psychedelics as therapies for depression and PTSD. MindMed in New York is developing a platform to help patients determine which drugs to take—therapeutics based on MDMA and DMT—depending on genetics and other data.

Scientists are learning more every day about the relationship between our gut microbes and our bodies.

Image credit: Future Today Institute and Dall-E.

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eDNA Detection

Environmental DNA, or eDNA, is genetic material found in the environment. Feces and fur from animals, as well as hair and saliva from humans are just some of the organic matter found in soil, seawater, snow, and air. As a fish moves through water, it's continuously shedding bits of itself. Likewise, when a cyclist rides on a trail, her sweat, mucus, and dead skin cells wind up mixed into the gravel and dirt. These fragments of nuclear or mitochondrial DNA can reveal invaluable insights about an environment. Scientists from the United States Geological Survey and the Monterey Bay Aquarium Research Institute are developing a new mobile eDNA sampler that can float through rivers and streams, collecting material and detecting pathogens or invasive species autonomously. As detection systems advance, eDNA detection will serve as early warning systems for potential outbreaks. But there's another interesting use for eDNA: reconstructing ancient ecosystems. Scientists excavated eDNA from frozen soil in the Arctic desert, and were able to piece together a lost world nearly 2 million years old. The eDNA revealed a coastal forest with conifers, black geese, horseshoe crabs, lemmings, and mastodons—a natural wonderland unlike any in existence today.

Using CRISPR for Sustainable Wood Production

Trees are a valuable natural resource, but improving their wood through traditional breeding is slow and complicated due to their complex genetics. CRISPR technology offers a way to quickly change trees to improve their wood—optimizing it for paper-making or reduced carbon emissions, for example. Scientists have used CRISPR to change multiple genes in poplar trees, resulting in wood that's easier to process and better for the environment. This breakthrough means we can now grow trees that are more suited for our needs while also helping the planet. The key challenge has been dealing with lignin, a natural part of wood that's tough to break down. But by precisely editing genes related to lignin, researchers at North Carolina State University have created poplar trees with wood that's much easier to turn into fiber. These advancements could make forestry more sustainable and efficient, offering new economic and environmental benefits.

Better Plastics Recycling

Despite global efforts to recycle plastic products, there are numerous barriers: Consumer-facing plastics come in different varieties, they're often coated with labels or print, and they have colors and other added features. The mess of waste—used iPhone cases, empty shampoo containers, soda bottles—can't be easily managed at scale, so a lot of it piles up. A potential solution is microorganisms like some bacteria and fungi that use special enzymes to break down various types of plastics. But turning plastic into something these microbes can eat isn't as simple as just mixing them together. The plastics need to be pre-damaged by sunlight or chemicals, and the microbes need just the right conditions to do their work. Even so, each type of microbe can only eat certain plastics, and it can take them weeks or months to break down just a small amount.

Now, an emerging synthetic biology process offers a new solution. France-based Carbios developed a process using an enzyme that's especially good at breaking down PET plastic into its basic building blocks, making it possible to recycle PET into high-quality new plastic. After improving the enzyme and testing it in an industrial setting, Carbios is now building its first site dedicated to this bio-recycling process. Meanwhile, researchers at SLAC National Accelerator Laboratory and the National Renewable Energy Laboratory used a microporous material called a zeolite that contains cobalt nanoparticles as a catalyst to break down different polymer molecules, turning the majority into propane. At the University of Texas at Austin, researchers used a machine learning model to generate novel mutations to natural enzymes that allow bacteria to break down the plastics found in soda bottles and most consumer packaging. The enzyme, called FAST-PETase (functional, active, stable, and tolerant PETase), could operate efficiently and work at an industrial scale. The first real-world application: setting the enzyme loose to clean up landfills.

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Engineering Plants for Carbon Capture

Carbon dioxide is the undisputed culprit when it comes to climate change. But what if we could just suck it out of the air? Trees do that naturally, but with deforestation, there's not enough to make a sizable impact. The Salk Institute's Harnessing Plants Initiative is working on an innovative approach that relies on our existing carbon storage mechanisms to help solve climate change. It's developing engineered crops that can store more carbon in the ground for long periods of time. The crops have a larger root mass, are deeper, and contain more suberin, a plant tissue that already relies on CO2 and can store significant amounts without causing harm to the plant. Salk researchers are hoping to develop strains of rice, wheat, corn, and other plants that both produce edible crops and store carbon, for improved soil health. Meanwhile, an artificial leaf developed at Harvard harnesses solar energy. When connected to a strain of bacteria, it converts atmospheric CO2 and nitrogen into organic forms that can benefit living organisms. Those hungry, solar-fed bacteria essentially overeat, to the point where

30% of their body weight is excess energy—stored CO2 and nitrogen. These microbes then get mixed into soil, and release all that nitrogen near the roots of plants, acting as an organic fertilizer. At that point, they also release the CO2, yet it remains trapped underground. The result: enormous crop yields without the environmentally poisonous side effects typically associated with chemical fertilizers.

Greening Fashion

The textile and clothing industry is a notorious polluter but is making steps toward more sustainable practices. Fuzhong Zhang, a professor at Washington University in St. Louis, has advanced the production of synthetic spider silk, which could lead to sustainable clothing manufacturing. Using synthetic biology, his team created a process to yield more silk from microbes, aiming to meet the fashion industry's demand for renewable materials and reduce the environmental impact associated with clothing production. By incorporating a protein from a common shellfish—mussels—the team de-

veloped silks that are stronger, tougher, and lighter than previous versions, with an eight-fold increase in yield. This innovation could provide an eco-friendly alternative to traditional textiles, drastically reducing waste in the fashion industry. The engineered silk, combining mussel foot proteins with spider silk properties, has already reached production levels sufficient for real-world product testing, marking a significant step toward its commercial use. Already, several other successful trials of synthesized textiles have occurred: Bolt Threads developed a synthetic fabric called Microsilk that's engineered from spider DNA, and Japanese startup Spiber synthesized enough fibers to manufacture a limited-edition parka. While manufacturing new textiles is on the horizon, getting bio-sourced materials such as PHAs, spider silk, and chitosan into the supply chain process remains a challenge. Mills and manufacturers don't have incentives to risk using new materials that may not work seamlessly with their existing production equipment.

The Salk Institute's Harnessing Plants Initiative is working on an innovative approach that relies on our existing carbon storage mechanisms to help solve climate change.

Image credit: Salk Institute.

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De-Extincting Lost Species

Woolly mammoths were once a "keystone species," one that other species in the ecosystem depended on in many ways for stability. They stomped around in herds, knocking down trees and packing down snow layers as they searched for dead grasses to eat, and that helped keep the permafrost layer stable. Once the mammoths and other large grazing animals stopped compacting the snow and eating dead grasses, the ecosystem began to change: The snow melted more easily, which allowed the sun to reach the permafrost. The permafrost layer is now melting at an alarming rate and releasing greenhouse gasses into the atmosphere, which creates a vicious cycle: Hotter temperatures lead to more melting, which releases more gasses, which causes hotter temperatures, and on and on it goes. Researchers are helping to de-extinct the woolly mammoth and other species using synthetic biology techniques: Starting with a fully intact healthy cell from a closely related species and working backward, with genetic fragments from preserved specimens, they could develop a version of the animals that once existed.

Rewilding Barren Terrains

Rewilding is a direct human intervention into nature using technology and science, a holistic approach to conservation that focuses on restoring the natural phenomena of wilderness ecosystems, providing connective corridors between wild spaces, and reintroducing keystone species to their natural habitats. A term coined more than 30 years ago, "rewilding" has gained renewed attention in the past few years as the climate crisis has grown more dire and new technologies have promised to protect and rehabilitate ecosystems. In 2017, researchers plunged into the waters off Lizard Island on the northeastern coast of Australia with some unexpected equipment in tow—a set of underwater loudspeakers. Their destination was a coral reef that had been all but abandoned by a once-thriving population of sea life. The researchers hoped that by broadcasting the telltale sounds of a healthy reef, they might lure back some of its vital inhabitants. Remarkably, it worked. This experiment was a unique instance of rewilding, but there have been others. In 2022, four bison were released in a woodland near Canterbury—the hope is that over time, the herbivores will revitalize a stretch of southeast England and allow vegetation to grow again, which should in turn boost biodiversity.

CRISPR Mosquitoes

Gene-drive technology, which has the potential to spread antimalarial genes among mosquito populations, is showing promise. Malaria kills hundreds of thousands of people every year; 96% of the deaths are in African countries, and particularly impact children under age 5. The idea of gene drive, which uses special DNA pieces that copy themselves and spread quickly through an organism's genes, was thought of years ago. However, it had problems because these DNA pieces could end up in important parts of the genes and cause harm. CRISPR-Cas9 technology, which allows for precise genetic edits, enables the safe transfer of antimalarial genes from one generation of mosquitos to the next. This advancement offers hope for controlling malaria by genetically modifying mosquitoes to resist or eliminate the disease. There have now been several pilots around the world to edit mosquitoes so they no longer carry malaria. In 2021, biotech company Oxitec launched a controversial field test of specially engineered mosquitoes in Florida in a move toward reducing the spread of deadly diseases such as dengue, yellow fever, and the Zika virus. Its tiny capsules contain an engineered form of the Aedes aegypti mosquito, called OX5034. Because only female Aedes aegypti bite and spread disease, Oxitec engineered males to pass on a gene that kills female offspring before they mature. Male offspring then continue mating and passing on the altered gene, which should change the population of disease-carrying mosquitoes. The US Environmental Protection Agency said this pilot poses no human threat, while local authorities, who have been dealing with steadily growing cases of dengue fever and West Nile virus, hope that a smaller mosquito population will curb the diseases without insecticides or poisonous chemicals. The EPA later approved an expanded plan to release 2.4 million genetically engineered mosquitoes in more US sites, including California. Similar
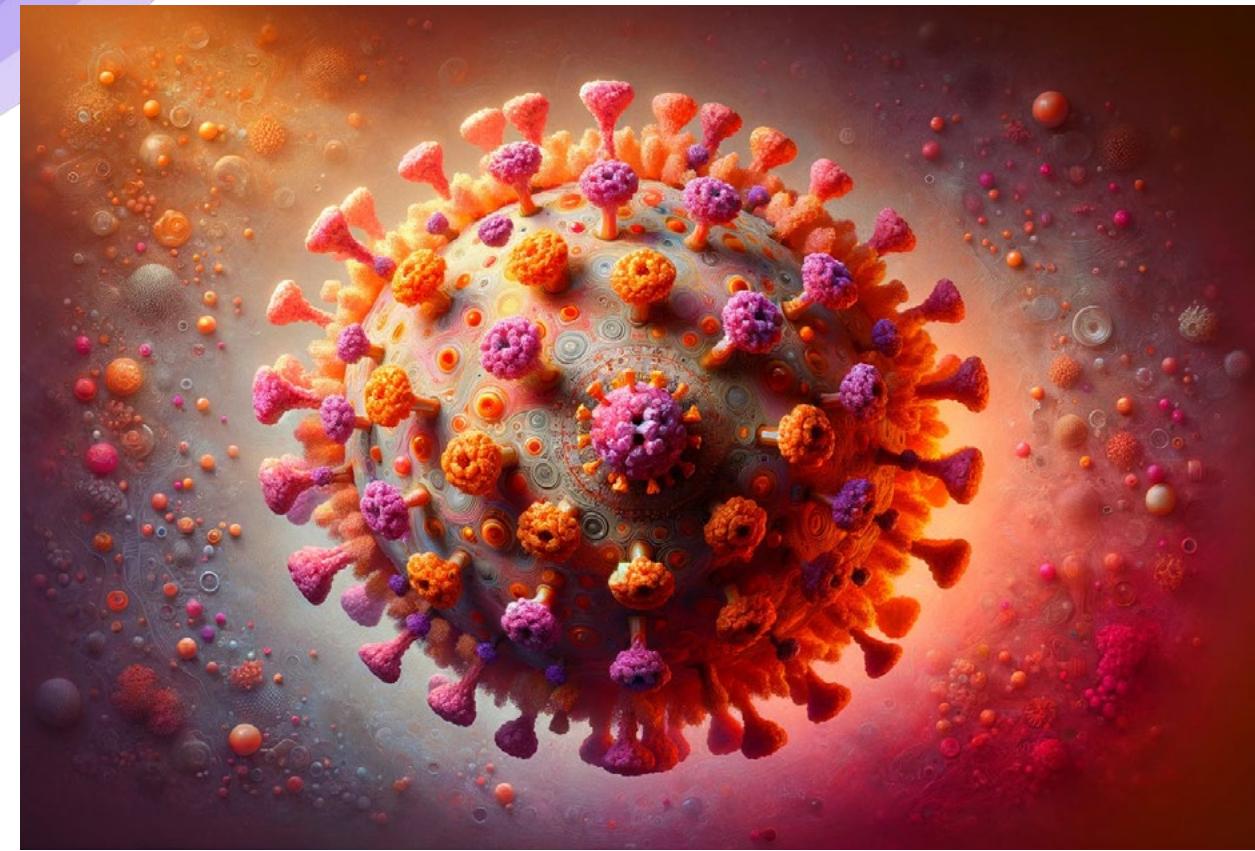
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experiments are underway in Malaysia and Panama. While they can transmit malaria, researchers are also thinking about how to use engineered mosquitoes to deliver a defense against deadly viruses. What if in the future mosquitoes are flying syringes capable of delivering vaccines? University of Washington scientists are working on a weakened form of malaria-causing Plasmodium parasites that won't get people sick but will cause the body to create antibodies. On the other hand, could meddling in the genetic code of insects, reptiles, and animals have catastrophic consequences that no one anticipates? If that sounds familiar, it's because you've seen that movie before: "Jurassic Park."

Reviving Ancient Viruses

As the Arctic warms, the thawing permafrost is raising concerns about the release of ancient viruses that could pose health risks to animals and humans. Scientists highlight the potential danger of these long-dormant viruses, along with the release of chemical and radioactive waste from the Cold War era, emphasizing the importance of keeping permafrost frozen. The permafrost acts as a natural time capsule, preserving not only viruses but also extinct animals, which scientists have been able to study. The rapid warming of the Arctic threatens to disrupt this frozen archive, with temperatures there rising up to four times faster than the global average. Research into "zombie viruses" found in Siberian permafrost has shown that some of these viruses are still infectious, which could mean a potential future risk of outbreaks from ancient pathogens. Global warming and increased activity in the region could heighten the possibility of a spillover event. Scientists advocate for proactive surveillance and research to understand the risks posed by thawing permafrost and to mitigate the impact of climate change on the release of pathogens.

As the permafrost layer melts, ancient viruses could thaw and release pathogens harmful to the modern world.

Image credit: Image credit: Future Today Institute and Dall-E.

REGULATION AND POLICY

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Regulatory Changes Toward Genome-Edited Crops

Starting last year, countries have been reevaluating their regulatory stance on genome-edited crops, marking a significant change in agricultural biotechnology policies. China's recent safety assessment guidelines for these crops show a partial shift from traditional regulations on genetically modified organisms, signaling a move toward a more nuanced approach that seeks to balance scientific innovation with public trust. Last July, the European Commission proposed legislative changes to relax the rules on gene editing, suggesting a departure from stringent GMO laws for certain next-generation techniques. This proposed legislation argues that edits achievable through traditional breeding methods should not be subject to the same stringent regulations as GMOs, streamlining the approval process for these innovations. Still, more complex modifications involving foreign DNA would still fall under existing GMO regulations, maintaining a layer of oversight on more radical genetic alterations. However, there is still no global framework, and as we've seen already, biology has a tendency to replicate and evolve in unpredictable ways. The developments in China and the EU reflect an urgent global need to update and reform regulatory frameworks for genome-edited crops, driven by a desire to foster innovation while ensuring safety and maintaining public confidence. As countries continue to adapt their policies, further changes will shape the future of agricultural biotechnology, potentially making genome-edited crops more accessible and widely used across the globe.

Regulating DNA Recognition Systems

Can you produce a photo of someone's face solely from their DNA? In the US, police detectives used a DNA sample to generate a 3D model of a suspect's face using facial recognition tools. Detectives from California's East Bay Regional Park District Police Department decided to use genetic information from a 1990 cold case involving the death of Maria Jane Weidhofer to create a lead. They sent the DNA from the crime scene to Parabon Nano-Labs, which specializes in generating faces from DNA. Using machine learning, Parabon produced a 3D image of a potential suspect based on the DNA evidence—not a real photograph but a predicted appearance including skin tone, eye and hair color, and other facial features. The company even incorporated a haircut and mustache based on a witness' description, not the DNA. In a move to gather public tips, the police department released this generated face, leading (unsurprisingly) to controversy. In 2020, more controversy ensued when a detective requested to run the DNA-based facial reconstruction through facial recognition software, a move considered problematic by civil liberties experts and against Parabon NanoLabs' policies. But while this was one of the first known instances of a police department using this tactic, the question of how and when to use someone's DNA is increasingly common. The COVID-19 pandemic accelerated widespread use of infectious disease surveillance techniques, from saliva tests at airports and border crossings, to nasal swabbing at testing centers. To ease testing bottlenecks, which sometimes resulted in hours-long lines, alternative testing centers opened up: Private companies dispatched workers, who often had no medical training, to vans or small tents to administer PCR or rapid response tests. It wasn't immediately clear where the test results would be sent, or who might also gain access to the data. With the growing size and scale of third-party test results and genetic databases, anyone with the right skills could identify individuals—and we don't yet have safeguards against widespread genetic surveillance. As of the start of 2024, there are few restrictions on private companies buying and selling genetic data in the US and in many places around the world.

Safeguarding Genetic Privacy

Genetic privacy will be increasingly difficult to safeguard—yet big genetic data sets are required to perform the kind of research that leads to new therapeutics. Sharing a person's complete genetic code online can help scientists but also poses privacy risks, as people with bad intentions might use it to learn about the health of an individual or their family. Recently, experts have started using AI to generate artificial, but scientifically useful, genetic data that keeps people's identities safe.

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Scientists at the University of Tartu, Estonia, use neural networks to develop novel segments on human genomes. Because genetic data is sensitive, the hope is that an artificial human genome will allow researchers to study DNA without infringing on anyone's privacy. Researchers at the University of Montpellier in France developed a novel method that uses both AI and known information about how genes change in our bodies to work with big data sets more easily. They cut genetic data from thousands of people from different backgrounds into pieces, based on where genes often mix during reproduction, and used it to train the AI system. It now creates artificial populations of genetic data that are diverse and realistic but don't risk anyone's privacy.

Defining Parenthood

The relationship between creating a child and being the parent of that child is becoming more complex due to advances in reproductive technology and changes in the law. Emerging technologies like induced pluripotent stem cells (see: Growing Sex Cells trend) will someday allow children to be conceived with synthetic eggs and sperm or grown in artificial wombs, challenging society's current ideas about procreation and parenthood. In the UK, regulators are considering reforms to make surrogacy simpler and to address the issue of commercial surrogacy, which is technically illegal but practiced in a gray area. One controversial proposal is to allow surrogacy without a genetic link between the child and the commissioning parents, which raises questions about whether this constitutes assisted reproduction or a form of adoption. The reforms also consider granting commissioning parents full parental rights from birth, moving away from the surrogate's default parental rights. These discussions highlight the tension between the desire for genetic parenthood and reproductive freedom, especially in cases where a biological connection to the child does not exist. Such debates will become increasingly relevant with the introduction of technologies like ectogenesis, potentially redefining what it means to "make" a baby and become a parent.

National DNA Drives

Several countries are in the process of developing their own national DNA databases, notably for the purpose of medical research advancement. The United Arab Emirates is currently working to sequence its entire population; the goal is to aid scientific research, as well as to map and sequence the genes of UAE nationals, which will assist in preventing and treating chronic illnesses. Because existing databases are overwhelmingly made up of Caucasian Americans and Europeans, people of Arab descent have been excluded from the benefits of genetic research. While the UAE's program is voluntary, there is a different strategy being used in China. Over the last decade, China has launched a comprehensive national effort to collect, sequence, and store the genetic information of its citizens, integrating DNA databases into a broader surveillance system fueled by the government's ambitions in artificial intelligence. This initiative has particularly targeted the Uyghur population, under the guise of public health programs like "Physicals for All," leading to the collection of genetic data without clear consent and raising concerns over privacy and human rights violations. As China builds a vast and unparalleled genetic database, encompassing both minority groups and the majority Han Chinese population, it faces minimal domestic opposition to its genetic research and surveillance practices, contrasting with the ongoing debates over genetic privacy in the US, Canada, the EU, and the UK.

International Collaborations to Advance Bioengineering

Researchers are building the first-ever comprehensive map of all 37.2 trillion human cells in the body. The effort includes 130 software engineers, mathematicians, computational scientists, biologists, clinicians, and physicists hailing from Israel, the Netherlands, Japan, the UK, the US, and Sweden. Although a cell atlas has long been theorized, new biological tools and more powerful computers have turned this one-time vision into a reality. These scientists believe this mapping will give the medical community a new way of understanding how our bodies work and will help diagnose, monitor, and treat disease.

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Resolving Bias in Genome Research

Overwhelmingly, the majority of people who have had their genomes sequenced come from affluent Caucasian Americans and Europeans; fewer than 2% are from Africa. This excludes an enormous number of people from the benefits of genetic research, so there is now increased attention and funding to diversify this pool. H3Africa works with African investigators to determine genomic and environmental determinants of common diseases. The Non-Communicable Diseases Genetic Heritage Study consortium, based in Nigeria, is creating a comprehensive catalog of human genetic variation among Nigerians. A decade-long Three Million African Genomes project is also underway to locate missing genetic variants from ancestral genomes in Africa. It would build an African biobank of clinical information and could lead to a more equitable future of genetic research.

Ethics in Indigenous Genomics

Biological materials from Indigenous peoples are still missing from genetic databases, basic research, and clinical studies. One major reason why can be traced back to how members of the Havasupai tribe were treated by Arizona State University (ASU) in the late 20th century. In 1990, Havasupai were grappling with an increase in diabetes. They allowed ASU researchers to collect blood samples, hoping the research would help them eradicate the disease. But then, unbeknownst to the Havasupai, the researchers changed the scope of the project to encompass genetic markers for alcoholism and various mental disorders. They went on to publish many papers in academic journals highlighting their results, which led to news stories about inbreeding and schizophrenia among tribe members. The Havasupai were, understandably, horrified and humiliated, and they filed a lawsuit against ASU in 2004. ASU eventually settled the suit in 2010, returned the blood samples to the tribe, and promised not to publish any more research. Subsequently, the Navajo Nation, the second-largest group of Indigenous peoples in the US, banned all genetic sequencing, analysis, and related research on its members. Although their objections were absolutely warranted, they've led to another problem: The pool of genetic data in the US doesn't include Indigenous peoples. New initiatives could make genetic datasets and research more inclusive. The Summer Internship for Indigenous Peoples in Genomics trains budding scientists, while the Center for the Ethics of Indigenous Genomic Research works to promote Indigenous-led research in biobanking and precision medicine. Canada and New Zealand are both working on governing frameworks and libraries to include Indigenous peoples, relying on direction from local communities.

Posthumous Sperm Retrieval

In the wake of the Hamas terrorist attack on October 7, 2023, when hundreds of young men were among the Israelis who lost their lives, there was an unprecedented surge in requests for posthumous sperm retrieval (PSR) by embryologists and IVF specialists. This process involves retrieving viable sperm from the deceased's testicular tissue shortly after death and preserving it in liquid nitrogen. Families sought to preserve their loved one's genetic legacy by extracting and freezing their sperm, hoping for the possibility of conceiving a child in the future. As a previously rare procedure, PSR required a family court order in Israel for unmarried men, while the spouse of a married individual could directly request the procedure. But the crisis led to Israel's Ministry of Health easing regulations, allowing hospitals to process requests from parents without court involvement. It also brought PSR into mainstream view, raising questions about whether it is ethical to retrieve and use sperm after death.

Gene Editing Ethics

In 2018, Chinese scientist He Jiankui caused a global uproar by announcing he had created the world's first gene-edited children using CRISPR technology, targeting embryos to make them resistant to HIV. This led to the birth of twins, marking a controversial milestone in genetic editing. Jiankui's actions, deemed "illegal medical practices" in China, resulted in a three-year prison sentence for him and his two associates, partly because the genetic alterations could be passed down to future generations. Following the scandal, China

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tightened regulations on human gene editing and banned He from conducting any reproductive technology services. Despite these restrictions, late in 2023, He proposed a new study focused on editing mouse and human embryos to investigate potential protection against Alzheimer's disease, citing the urgent need to address the challenges posed by an aging population and the current lack of effective treatments for Alzheimer's. His latest proposal has reignited ethical debates and concerns within the scientific community. The proposal's reception remains mixed, reflecting ongoing dilemmas over the boundaries of genetic research.

A dozen countries have now banned germ line engineering in humans, though their ranks do not include China, which tightened regulations without banning the practice outright. Federal law in the US regulates the use of federal funds for research on human germline gene therapy—laws are notoriously politicized and have changed a few times in the past decade. The EU's Convention on Human Rights and Biomedicine said tampering with the gene pool would be a crime against human dignity and human rights. But all those declarations were made before it was actually possible to precisely engineer the germ line. Now, with CRISPR, it is possible.

Engineering Super Soldiers

Last year, a team of military medical scientists in China reported that they had enhanced human embryonic stem cells' resistance to radiation by inserting a gene from the water bear, a microorganism known for its extreme survivability. Using CRISPR technology, they achieved a high survival rate of these modified cells under lethal radiation exposure. The research, led by professor Yue Wen at the Academy of Military Sciences in Beijing, has sparked interest (read: alarm) since its publication, because of the implication: What if this is used to create a new version of superhumans, capable of surviving extreme conditions like nuclear fallout? Scientists around the world raised concerns about the safety and ethical implications of transferring genes across species, with the risk of harmful mutations or unknown immune responses. The team plans to further their research by transforming these modified cells into blood-making cells to help humans survive acute radiation sickness, suggesting additional benefits in protecting against diseases such as cancer and diabetes. The experiment was deemed legal as it was conducted on cultured cell lines in a lab. But what happens when that research is ready to leave the lab for the real world?

Some researchers are concerned that biological experimentation could someday produce supersoldiers who have been enhanced with special capabilities.

Image credit: Image credit: Future Today Institute and Dall-E.

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Recognized as the global leader in strategic foresight, Amy Webb advises business leaders through disruptive change, enabling them to navigate an unpredictable future with confidence and take actions that address global challenges, create sustainable value, and ensure a company's long-term growth. As founder and CEO of the Future Today Institute, Amy pioneered a unique quantitative modeling approach and data-driven foresight methodology that identifies signals of change and emerging patterns very early. Using that information, Amy and her colleagues identify white spaces, opportunities, and threats early enough for action. They develop predictive scenarios, along with executable strategy, for their global client base. In 2023, Amy was recognized as the #4 most influential management thinker in the world by Thinkers50, a biannual ranking of global business thinkers. She was also featured on the 2021 Thinkers 50 list, was shortlisted for the 2021 Digital Thinking Award, and received the 2017 Thinkers50 Radar Award. Forbes called Amy "one of the five women changing the world," and she was honored as one of the BBC's 100 Women of 2020.

Amy also serves as a professor of strategic foresight at New York University's Stern School of Business, where she developed and teaches the MBA-level strategic foresight course with live case studies. She is a Visiting Fellow at Oxford University's Säid School of Business. She was elected a life member of the Council on Foreign Relations and is a member of the Bretton Woods Committee. She is a Steward and Steering Committee Member for the World Economic Forum, a founding member of the Forum's Strategic Foresight Council, a member of the Forum's Risk Advisory Council, and serves on the Forum's Global Futures Council. She was a Delegate on the former U.S.-Russia Bilateral Presidential Commission, representing US interests in technology.

Regarded as one of the most important voices on the futures of technology (with specializations in both AI and synthetic biology), Amy is the author of four books, including the international bestseller The Big Nine and her most recent, The Genesis Machine, which was listed as one of the best nonfiction books of 2022 by The New Yorker. To date, her books have been translated into 19 languages. A widely published and quoted thought leader, Amy regularly appears in a wide range of publications and broadcasts.

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ENERGY · CLIMATE

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TOP HEADLINES

Private and public climate efforts widen and accelerate in the light of the most extreme weather we have ever experienced

01 Investment is shifting from clean energy to enabling technologies

As wind and solar provide more power, venture capital is targeting bottlenecks in supporting infrastructures such as the grid and monitoring technology.

02 Extreme weather sets new records

2023 was the hottest year in the history of humankind; as the ocean warms, the collapse of the Gulf Stream is projected to be much more likely.

03 Tracking carbon has become popular with regulators

Regulators have shifted their focus from establishing the carbon market to adding transparency, standards, and verification frameworks.

04 Polluters being held accountable

A slew of groundbreaking litigation set precedents for holding governments and companies accountable for the effects of climate change caused by their (in)action.

05 Governments are considering a broader set of tools

Regulators are exploring solar geoengineering, considering softer regulations for CRISPR crops, and redesigning urban concepts to adapt to hostile environments.

STATE OF PLAY

From revolution to evolution: The global focus shifts to the creation of an enabling ecosystem for climate action at scale.

In 2023, attention shifted from scaling of renewable energies and electric vehicles to ensuring that these scaled technologies could be viably integrated into existing systems. Venture capital moved from transportation, energy, and food and land use to the built environment and heavy industry decarbonization, making significant innovation likely. Governments tightened ESG regulations, putting pressure on companies to bring transparency into carbon emission reporting, even while standardization frameworks for measuring and reporting these emissions along the entire supply chain are still being developed. These increased reporting pressures run the risk of leading to a focus on the wrong metrics, crippling effective environmental initiatives.

Environmental impacts are now defined more broadly, which increases companies' responsibilities. The framework passed at the 2022 UN's Biodiversity Conference amplified the protection of biological ecosystems, equitable access, and human rights. In 2023, COP28 had its first-ever health day, and nations committed to include food systems into their updated Nationally Determined Contributions. Further responsibilities might come from a series of lawsuits which decide if actors can be held responsible for the effects of climate change they caused. If courts rule they are, prepare for drastically changed efforts in regulation and business practices.

KEY EVENTS

MARCH 8, 2023

Carbon injected in the sea
Denmark became the first nation to import CO2 for the purpose of burying it in the North Sea.

JUNE 29, 2023

Fraud task force for ESGs
The Commodity Futures Trading Commission announces a task force to combat ESG related fraud.

DECEMBER 3, 2023

First Ever COP Health Day
The acknowledgment of the interconnectedness of health and environment at the UN Climate Change Conference gives hope for integrated actions.

MARCH 14, 2023

Forever chemicals ban
In the US, toxic PFAS are banned from water while the EU backpedals.

JULY 5, 2023

Looser GMO rules in EU
The European Commission proposes looser restrictions in light of innovation in the field.

LIKELY NEAR TERM DEVELOPMENTS

CHANGE IS THE NEW NORMAL

Two opposing forces will make the corporate landscape highly volatile and unpredictable. On the one hand, active regulatory bodies, scaling of renewable energy production, and increased investment in innovation that aims to solve the remaining bottlenecks will require and empower corporations to integrate sustainability in ways not imaginable just a few years ago. On the other hand, economic headwinds in the form of heavy inflation and a looming recession might lead consumers to prioritize affordability over sustainability, and escalating geopolitical tensions could strain the supply chain, increase the price of raw materials, and hinder collaboration in research— slowing down innovation.

Price Beats Ethics

As inflation soars and the fear of a recession festers, consumers might put affordability above climate considerations, at least when it comes to their wallets. This will put additional strain on business owners, as they determine how to adjust for climate demands.

Shifts in Mobility

More and more people, at least in Europe, are committing to not use air travel. The resulting smaller spheres of mobility could lead to an increasing need for companies to have local hubs, especially as the terms of remote work are still being negotiated.

Rethinking Supply Chains

Governments are expanding their requirements for reliable and consistent reporting of direct and indirect emissions (scope 1, 2, and 3), putting pressure on corporations to curate their vendor networks and on the vendors to ensure their operations are still profitable under increased standards.

Accountability Changes

The resolution of a number of upcoming court cases will begin to determine government and corporate responsibility for climate change. If verdicts fall on the side of holding institutions responsible, we could see fundamental changes in how climate is addressed.

From Early Bird to Night Owl

Excessive heat impacts daily lives around the globe, forcing people to stay indoors during the day and only leave their houses in the evening. As these heat phases expand, industries dependent on people's physical presence will have to rethink operations as habits and timing of activities shift.

Climate Upskilling

With climate regulation expanding and evolving, and climate technology innovation accelerating (thanks to AI) and scaling, companies need to make sure they have the necessary know-how in-house to understand and monitor relevant developments.

11 MACRO SOURCES OF DISRUPTION
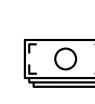
| Technology | Media & Telecom | Demographics | Environment | Government | Public Health | Education | Geopolitics | Infrastructure | Economy | Wealth Distribution |
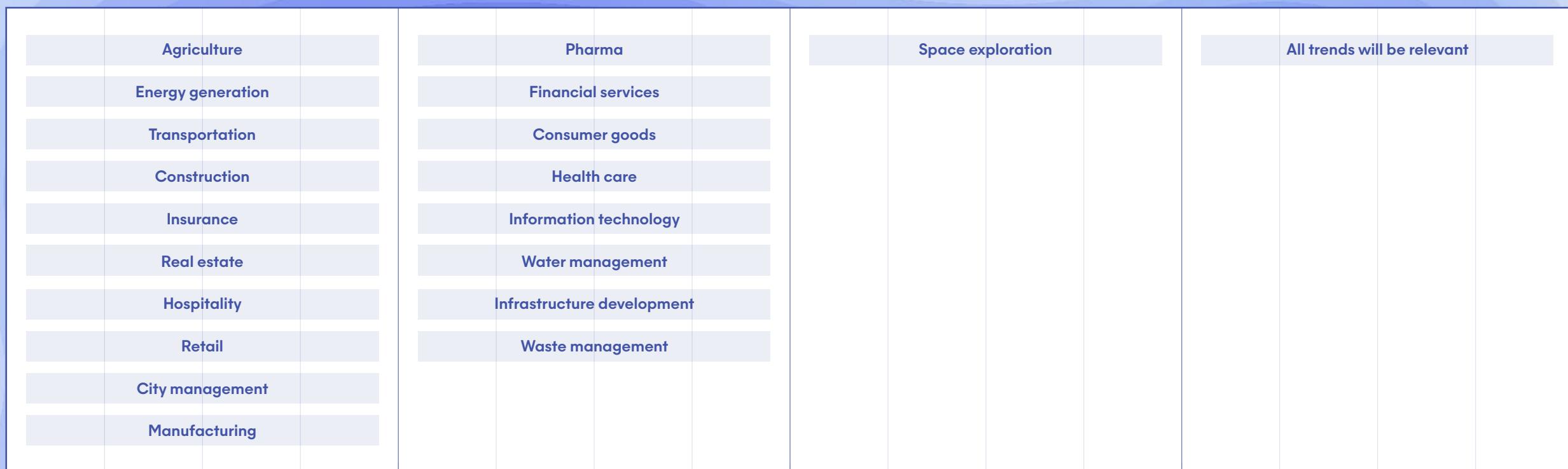
WHY ENERGY & CLIMATE TRENDS MATTER TO YOUR ORGANIZATION

Opportunity for Innovation

Energy and climate technologies can help businesses transform in revolutionary ways that increase profitability significantly: Changed processes, new materials, updated supply chains, a different set of partners and collaborators, and investment in research can lead to new products and services—and a competitive edge.

Cost Savings & Efficiencies

Embracing climate technology brings long-term savings. Reduced energy use and operational expenses enhance overall efficiency, positively impacting the bottom line. This positions the company for sustainable growth, demonstrates commitment to a green future, and fosters a culture of environmental responsibility.

Climate Risk Resiliency

Increased frequency, severity, and wider occurrence of extreme weather events force all businesses to think about how to mitigate impacts, not just those in disaster-prone regions. Flexible measures are needed to maintain continuity, protect assets, and promote sustainable growth in the face of an increasingly unpredictable climate.

Investment & Financing Opportunities

As climate-conscious funding continues to surge, businesses with innovative climate solutions gain greater access to capital, enabling them to scale operations and accelerate the transition to a more sustainable future. This provides a unique opportunity to stay ahead of regulatory requirements and tap into growing green markets.

Energy Independence

Businesses that invest in their own renewable energy production can achieve a high degree of energy independence, reducing their vulnerability to fluctuations in pricing and increasing grid failures. They'll gain greater control over energy supply, with insulation from market uncertainties and enhanced long-term stability.

Attack on Profitability

Implementing climate technologies and adhering to environmental regulations may raise production costs, due to upfront investment or compliance expenses, impacting profitability. Strategic planning and collaboration are crucial to navigating this transition successfully.

WHEN WILL ENERGY & CLIMATE TRENDS DISRUPT YOUR ORGANIZATION?

Forecasted Time of Impact

0-4 YEARS	5-9 YEARS	10-14 YEARS	15+ YEARS
Agriculture	Pharma	Space exploration	All trends will be relevant
Energy generation	Financial services		
Transportation	Consumer goods		
Construction	Health care		
Insurance	Information technology		
Real estate	Water management		
Hospitality	Infrastructure development		
Retail	Waste management		
City management			
Manufacturing			

OPPORTUNITIES & THREATS

Threats

Assessing the existing expertise and hiring or training employees with the necessary skills to integrate climate technologies is a must yet can be challenging in an already tight labor market and an overworked workforce.

Companies might be confronted with a much higher cost of doing business after integrating sustainable processes and raw materials. This might pose existential risks or fundamental shifts in operations and threaten profitability.

Geopolitical tensions and a higher frequency of extreme weather events increase the risk for supply chain disruptions, as well as rising prices and scarcity of necessary base materials and labor.

As tracking capabilities expand through scope 1, 2, and 3 emissions, businesses should be prepared to find that their carbon emissions footprint is much more significant than expected (and less under their control).

Proactive regulators are needed to ensure we reach our climate goals. However, new regulations as well as changes to existing rules will redesign business environments and create a strain for companies as they try to navigate their operational transformation.

Opportunities

Look for new partners to collaborate with and selectively outsource activities for implementing sustainability measures as part of a new supportive ecosystem. This keeps costs at bay and expands the opportunity for cross-pollination of ideas.

Price volatility and stricter regulation will trigger a rethink of business operations. This can lead to new efficiencies in tangential contexts outside of environmental considerations and positively affect margins.

First movers will be able to define the new normal. They'll build competitive advantage by transforming common business procedures in their industry and setting standards as they improve their business operations.

Think beyond the changes necessary to comply with sustainability requirements by also considering structural changes that could make the company more flexible and responsive to innovation.

Energy and captured CO_2 emissions are just two examples of products that the integration of climate technologies can add to a company's portfolio. Thinking expansively can open up avenues into new industries, including but not limited to energy.

INVESTMENTS AND ACTIONS TO CONSIDER

1

With innovation making huge strides in carbon tracking, invest time into finding the platform and sensor ecosystem that's the best fit for your business and supply chain. These technologies will touch every aspect of your business, making the implementation of new hardware and software very expensive.

2

Consider all workforce aspects: Companies need to weigh the skills and expertise available, where to hire or upskill, whether structure and hierarchies need to evolve, as well as where employees should be working. All these factors are relevant for the carbon footprint but also need to be considered for maximizing profitability.

3

Sustainability is becoming a broader effort and now includes biodiversity, ethical practices, and protection of indigenous communities. Work toward gaining insights about these areas throughout your entire supply chain to prepare for regulatory pressures.

4

Explore new avenues to not only stay on top of innovation but to become part of the ecosystem of investing, research and development. This ensures that the bottlenecks and problems specific to your business are being solved, and might even lead to new business models licensing the developed technology.

5

Global demographics will change significantly over the next few decades, with migration, aging, and overpopulation all contributing factors. Investigate how this affects your current customer base, and where new markets, either in regards to location or customer profile, could emerge globally.

6

Clearly define goals, benchmarks, and deadlines for the assessment and implementation of climate technologies in your company. Identify a sensible organizational structure, relevant stakeholders, responsible parties, and how the company will efficiently integrate the findings and technologies.

CENTRAL THEMES

Proactive Regulators

On both sides of the Atlantic, regulators stepped up to enable significant climate action. The EU's Green Deal Industrial Plan includes easier access to financing, simplification of permitting processes, regulatory sandboxes for member states, and the announcement of the European Hydrogen Bank to quickly scale the fuel's use in the region. In the US, regulators banned certain forever chemicals (PFAS) in drinking water, strengthened pollution standards for cars and trucks, and widened eligibility for clean-energy tax credits. To avoid greenwashing, the EU proposed the Green Claims Directive to eliminate misleading messaging. In the US, the Commodity Futures Trading Commission created a task force to combat environmental fraud, and the Securities and Exchange Commission proposed stricter climate disclosure rules for publicly traded companies.

Focus on Enabling Technologies

After passing the $1 trillion investment mark in 2022, overall venture capital in climate tech dropped 40% in 2023. However, most of that decrease took place in later stages and growth funding; seed funding actually grew 23%, and the number of deals rose by 34%. In addition, investors are showing enthusiasm for solving new problems, after renewables have moved into the scaling phase. Investment in the big three—transportation, energy, and food and land use—saw significant drops, while investment in industry processes and the built environment, both historically underfunded, saw gains. But there is still much to be done: Transforming the grid to accommodate non-dispatchable energy sources; searching for alternative materials for batteries, solar cells, and wind turbines; capturing and storing carbon; tracking emissions; and bringing transparency and validity to carbon markets are just some of the bottlenecks that urgently need innovation.

Alternative Materials

The race to find alternative materials for renewable energy production and tangential technologies (such as batteries) is on. In a tense geopolitical environment where the location of needed raw materials is limited to areas often plagued by political and economic instability, there's an increased desire for nations to be resource independent. Recently, Sweden and Norway made inroads on this independence when the largest rare earth and mineral deposits were found in the region. While China responded to the US's 2022 export controls on advanced computing and semiconductors manufacturing equipment with its own restrictions on exporting gallium and germanium (needed for solar technologies), impact is less significant thanks to the ability to expand in alternative markets in the midterm. Innovation intensified last year around finding alternative materials for climate technologies, predominantly in electric vehicle motors (rare earth) and batteries (metals).

CENTRAL THEMES

Looking Beyond Carbon

While carbon dioxide emissions are front and center in the climate conversation, a more holistic approach has gained significant traction and increased public awareness. Both the US and the EU have taken steps to control methane emissions, and global leaders came together during the United Nations Biodiversity Conference (COP 15) in December 2022 to agree on global action on addressing biodiversity loss, restoring ecosystems, and protecting indigenous rights. As a result, 30% of the planet and 30% of degraded ecosystems will be under protection by 2030. EU regulators have agreed on the Nature Restoration Law, which requires countries to work toward restoring at least 20% of land and sea areas, and the US expressed its intention to join the High Ambition Coalition on Biodiversity Beyond National Jurisdiction, supported by the UN. Currently, 95% of the ocean falls beyond national jurisdiction, and the coalition represents a group of countries that have pledged to protect that ecosystem. Rewilding efforts have also increased, often on state, local, and even individual levels.

Tracking Climate Change

The tightened regulatory requirements for companies to reduce their carbon footprint increases the need for cohesive and reliable emissions tracking, as well as common measurement standards. In the carbon credit market, frameworks to verify actual results of carbon projects and create a viable rating system are crucial for credibility and effectiveness. As extreme weather becomes more frequent, severe, and widespread, governments have increased their efforts to build better prediction systems to protect lives and ecosystems. Amid a landscape where insurers are pulling out of states like California and Florida because risks deemed uninsurable, these systems can provide the industry with the data necessary to calculate risks. The development of these monitoring technologies is being accelerated by artificial intelligence and innovation around imaging, such as hyperspectral imaging. Also helping to unify the integrity frameworks are joint efforts by various stakeholders in the voluntary carbon markets.

Blue Economy on the Rise

Originally used by small developing island states, the term "blue economy" today encompasses socially equitable, environmentally sustainable, and economically profitable ocean-based industries and spaces. In 2023, the US launched a global initiative of more than $800 million to protect oceans and support developing nations. This follows the EU's previous efforts to create the Atlantic Smart Ports Blue Acceleration Network to transform Atlantic ports, the G20 Supreme Audit Institutions cooperating to meet the challenge of auditing the blue economy, and African funds' focus on innovation to advance blue economy solutions for the continent. These initiatives triggered a flurry of innovation focusing on the ocean, from means and devices to collect data underneath the surface, to platforms that synthesize and analyze the data and make it available to all relevant stakeholders, to advanced desalination methods and increased support for sustainable fishing. As the ocean is also moving more into the climate conversation for carbon sequestration and power generation, we can expect to see an acceleration of not just technological advances but also novel business activity in this space.

ONES TO WATCH

Dr. Stefaan De Wolf, professor of material science and engineering of the KAUST Solar Center, for setting the world record for tandem solar cell efficiency.

Alexander Bormann, founder of EnerKite, for expanding the EV-charging infrastructure with airborne wind.

Dr. Motiar Rahaman, research associate at University of Cambridge, for leading research on a solar-powered reactor that converts CO_2 captured from industrial waste or air into sustainable fuel.

Andrew Ponec, co-founder and CEO of Antora Energy, for developing thermal energy storage that turns renewable energy into on-demand power usable by the heavy industries.

Xiaomeng Liu, researcher at University of Massachusetts Amherst, for his research on creating energy from air.

Mateo Jaramillo, CEO of Form Energy, for building a 1 gigawatt hour demo system of an iron air battery, expected to come online in 2025.

John Connell, senior scientist at NASA Langley Research Center, for advancing research on a solid state battery to be used in aviation.

Lee Suk-bae, Ji-Hoon Kim, and Young-Wan Kwon of the Quantum Energy Research Centre, for their preprint on developing the first room temperature superconductor.

Hudson Gilmer, co-founder and CEO of LineVision, for creating the only non-contact overhead power line monitoring system, used by UK's National Grid.

Isabella Arzeno-Soltero, postdoctoral scholar at Stanford University, for determining that seaweed farming cannot scale enough to meet climate goals.

Dr. Graciela Chichilnisky, co-founder of Global Thermostat, for creating one of the largest direct air capture machines ever operated.

Talal Hasan, CEO of 44.01, for leading the first CO_2 mineralization project in the Middle East that utilizes seawater.

Pasi Vainikka, CEO of Solar Foods, for creating food out of renewable energy and carbon dioxide.

Freddie Lintell, founder and CEO of Reewild, for creating a carbon tracking app for consumers.

Josh Dorfman, co-founder and CEO of Plantd, for transforming perennial grass into carbon-negative building materials.

Virginia San Fratello, architect, for 3D printing houses out of indigenous materials such as salt and clay.

Dr. William Dichtel, chemistry professor at Northwestern, and Brittany Trang, Sharon Begley Science Reporting Fellow at STAT, for developing a low temperature, inexpensive method to break down PFAS.

Shimrit Bar-El, co-founder and CRO at Novella, for growing botanical ingredients without the plant.

Hunter Swisher, founder of Phospholutions, for reducing the amount of phosphorus in fertilizer by 50%.

Nathalie Berezina, founder and CEO of Norbite, for transforming plastic waste into sustainable products with the help of moths.

Khaled Hassounah, co-founder and CEO of Ample, for providing an alternative to EV charging: battery swapping.

Tim Duehrkoop, co-founder and CEO of Xilva, for developing a methodology to assess forest sequestration projects.

Dr. Tom Jackson and his team at Loughborough University, for the creation of the "Data Carbon Ladder," which enables the tracking of digital emissions.

Bob Mumgaard, CEO of Commonwealth Fusion Systems, for being a frontrunner in the nuclear fusion race.

IMPORTANT TERMS

Ammonia
A compound of nitrogen and hydrogen. It can be used directly as a fuel in direct combustion processes, as well as in fuel cells or as a hydrogen carrier. To be a low emissions fuel, ammonia must be produced from low-carbon hydrogen and the nitrogen separated through the Haber process using electricity generated from low-carbon sources.

Bioenergy
Energy content derived from biomass feedstocks and biogas. It comes in solid, liquid, and gaseous form. Its liquid form is often labeled biofuel.

Biogas
A mixture of methane, CO_2, and small quantities of other gases produced by anaerobic digestion of organic matter in an oxygen-free environment.

Carbon capture, utilization, and storage (CCUS)
The process of capturing CO_2 emissions from fuel combustion, industrial processes or directly from the atmosphere. Captured CO_2 emissions can be stored in onshore or offshore underground geological formations, or used as an input or feedstock in manufacturing.

Direct air capture
A technology that captures CO_2 from the atmospheric air through a chemical reaction.

Dispatchable generation
Dispatchable generation is a source of electricity that can be turned on or off, such as nuclear, meaning it can be controlled. Non-dispatchable energy sources, such as wind and solar photovoltaics, cannot be controlled by operators.

Electrolysis
Electrolysis is a process where electric current passes through a substance to effect a chemical change. In hydrogen production, electricity is used to split water into hydrogen and oxygen. If the power used for the process comes from sustainable energy sources, the process does not produce greenhouse gas emissions.

Energy intensity
Energy intensity is the amount of energy used to produce a certain level of output.

Hydrogen
Hydrogen is the simplest and most abundant element in the universe. It can be produced from a variety of resources such as water, fossil fuels, or biomass, and used as a source of energy or fuel. Depending on the resource and energy type used to produce it, hydrogen production can be emissions-intensive or carbon neutral.

Liquid bioenergy (biofuel)
Liquid fuels derived from biomass or waste feedstock. They include ethanol, biodiesel, and biojet fuels.

Conventional: Fuels produced from food crop feedstock such as sugar cane or vegetable oil, among others.

Advanced: Fuels produced from non-food crop feedstock that don't directly compete with food and feed crops for agricultural land.

Process emissions
Emissions from industrial processes that involve chemical or physical transformations (separate from fuel combustion).

Pyrolysis
Pyrolysis is the process of heating organic materials, such as biomass, in the absence of oxygen.

Solid bioenergy
Charcoal, fuelwood, dung, agricultural residues, wood waste and other solid wastes.

Traditional: Refers to the use of solid biomass with basic technologies, such as a three-stone fire, often with no or poorly operating chimneys.

Modern: Refers to the use of solid bioenergy in improved cook stoves and modern technologies using processed biomass such as pellets.

Solar photovoltaics (PV)
A process which converts sunlight into electricity using a technology based on the photoelectric effect. With the photoelectric effect, materials absorb photons (light) and release electrons, generating electricity.
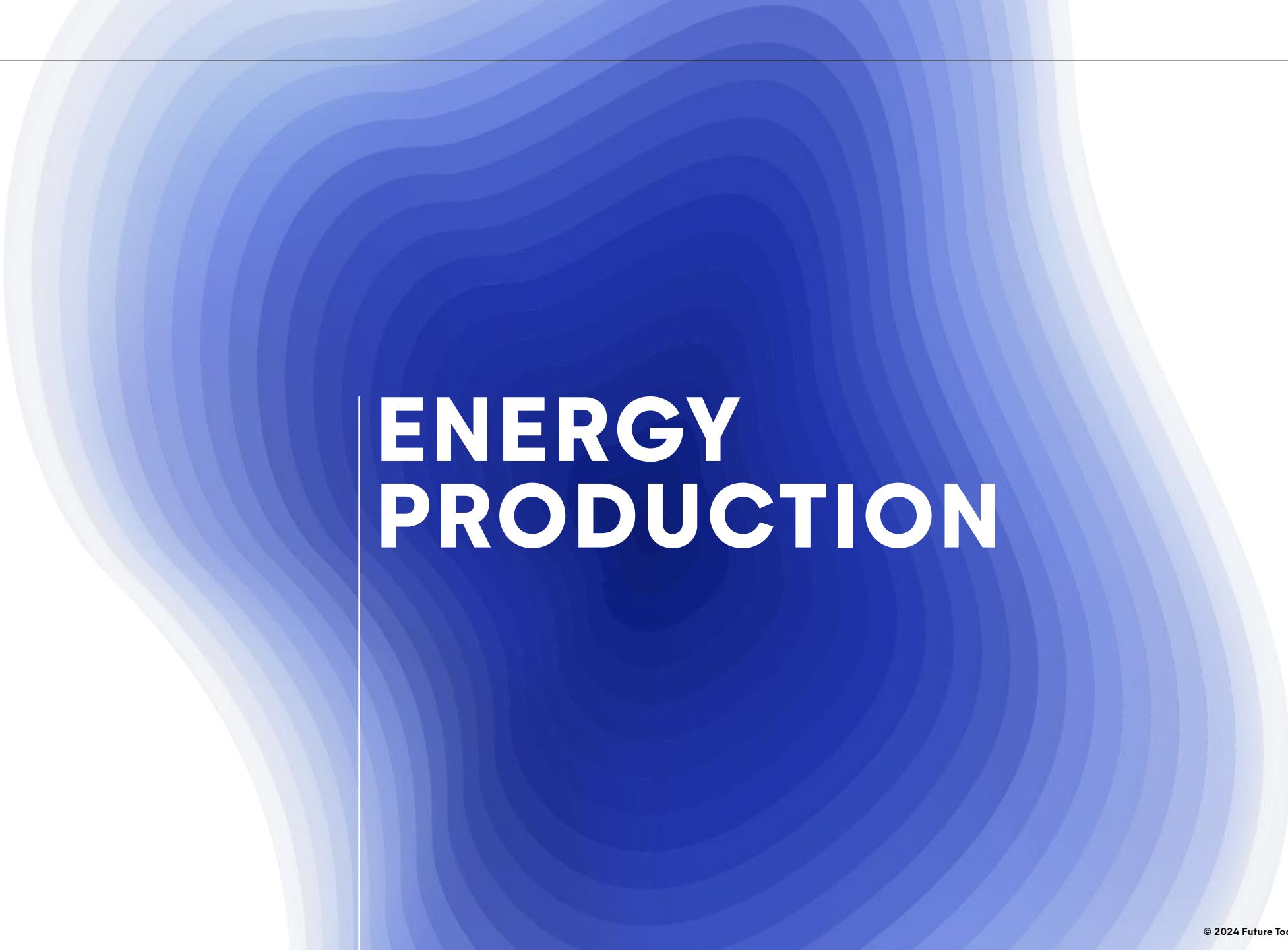
Zero carbon-ready buildings
A zero carbon-ready building is a highly energy efficient building. It uses either renewable energy sources directly or energy sources that can be decarbonized, for example electricity or district heat.

Zero emission vehicles (ZEVs)
Vehicles that operate without emitting CO_2 emissions (such as battery electric and fuel cell vehicles).

ENERGY PRODUCTION

NEW SOLAR

Concentrated Solar

Concentrated solar power (CSP) uses parabolic mirrors or "heliostats" to focus sunlight and generate extremely high temperatures. A common implementation of CSP is the "power tower," in which concentric circles of heliostats all focus on the receiver of a single, central tower hundreds of meters off the ground. Although the concept was first developed in the 1970s and '80s, new methods and plant designs have inspired a modest resurgence, particularly in Australia and Africa. Bolstering the case for CSP plants is the dispatchability of the energy generated. Because CSP generates thermal energy, it can be transferred using liquid sodium and stored long term in molten salt reservoirs. Due to the abundance of the elements required, large-scale thermal storage would be relatively cheap when compared with the rare earth elements needed for electric batteries, such as lithium and cobalt. For this reason, concentrated solar is being viewed as an economical alternative to photovoltaic solar for nighttime use.

Multitasking Solar

Companies are building new solar installations with a mind toward additional benefits beyond electrical power generation. When installed in tandem with wind turbines, solar panels are arranged to take advantage of the Venturi effect, essentially creating wind tunnels. These configurations increase airflow and wind turbine output by up to 60%. Solar windows are becoming transparent enough not to impact aesthetics in building construction, thanks to organic semiconductors that can be liquified and spread as a coating on glass. In California, a pilot program dubbed Project Nexus is placing solar panels above irrigation canals in the San Joaquin Valley. Researchers estimate that placing similar solar panel canopies above the state's 4,000 miles of open canals would generate 13 gigawatts of power while simultaneously saving 63 billion gallons of water annually in a region that has seen severe drought over the past decade. The solar canopies cool water temperatures, halt evaporation, and prevent the growth of water-based plants.

Dispatchable Solar

Dispatchable power enables a generation source to scale up or down based on fluctuations in demand. Solar power installations, traditionally implemented in a way that always maximizes energy output, are getting smarter, able to adjust individual panel angles to change their aggregate power generation and better accommodate the needs of the grid. On large-scale solar farms, this system of dispatching can go so far as to independently adjust subsections of panels, or even individual panels, to compensate for others that are temporarily obscured by cloud cover or experiencing operational issues, thus ensuring a responsive and consistent output. Counterintuitively, many of the problems with static solar power generation stem from creating too much power: When the sun is at its zenith and solar generation peaks, solar plants can potentially produce so much energy they overwhelm local electric grids. Dispatchable solar power eliminates this problem, creating a more dynamic and responsive source of power.

Perovskite Cells

Perovskite is a crystalline compound that can be used as a semiconductor in solar cells as an easier, cheaper, and more sustainable alternative to silicon. Furthermore, it is transparent and flexible, making it easier than silicon to integrate into the landscape. In April, researchers at the King Abdullah University of Science and Technology in Saudi Arabia developed a new combination silicon/perovskite solar cell, which achieved an efficiency of 33.2%, a new world record for two-junction solar cells. Advances in perovskite-based cells are occurring quickly, and the technology is regularly setting new efficiency and lifetime records.

NEW SOLAR

Dye-sensitized Solar Cells

Dye-sensitized solar cells (DSC) are made using organic dyes that capture photons from light. They are cheaper to manufacture than silicon solar cells, more flexible in their design, and can even be semitransparent. Further, they operate on a wider spectrum of light than traditional silicon solar cells. Ambient Photonics, an Amazon-backed startup, has completed construction on a new, large-scale DSC manufacturing facility. The company claims its products can operate at low levels of light, such as indoor environments, and is aiming to eliminate the need for batteries in small electronic devices.

Organic Solar Materials

Organic solar materials that can be printed or stuck onto surfaces have continued to shrink in size. These photovoltaics can be 50 microns thin, less than the width of a human hair, and can be adhered to surfaces after they're manufactured, ostensibly making any surface a power-generating opportunity. Because of the small footprint of organic solar cells, they can also be adhered to transparent surfaces. As a result, solar windows are reaching the point where they are transparent enough not to impact aesthetics and could be used more widely in buildings. Recent experimentation aims to increase these organic solar cells' viability for power production on larger areas.

Solar Thermophotovoltaics

While normal photovoltaic cells respond only to less than half of the sun's rays that are visible, solar thermophotovoltaics create electricity from heat waves. Antora Energy, a US-based startup, has completed a large-scale manufacturing facility that produces thermophotovoltaic cells with 40% efficiency. Meanwhile, researchers at the University of Houston have developed a new design for thermophotovoltaic cells with an improved intermediary layer, which prevents thermal energy from being wastefully radiated away. This development could push efficiency levels even higher.

Flexible, transparent solar cells might soon be adhered to building windows.

NEW WIND

Offshore Floating Wind Turbines

Offshore floating wind technology is growing with changes in base designs, innovative turbine configurations, and strengthened regulatory backing in the US and Europe. In recent years, "super-sized" structures have become popular as major players unveil groundbreaking designs. Among these is Wind Catching Systems, a 2017-established entity situated near Oslo, Norway. Pioneering the multi-turbine approach, the company focuses on a "floating wind power plant." The Dublin-based Gazelle, a company focused on advanced offshore wind platforms, has introduced a new hybrid dynamic mooring system—this revolutionary platform design promises unmatched stability, courtesy of its lightweight and compact structure and flexibility as it can be seamlessly assembled at global port facilities. In the realm of US regulation, the Biden administration has announced a comprehensive 20-month study of the West Coast's burgeoning floating offshore wind potential. This investigation aims to optimize transmission networks and connect the grid with pioneering floating wind projects; it will be supported by a $100 million public fund.

Vertical Wind Turbines

Vertical wind turbine innovation reached a milestone with Norway's March 2022 approval of a vertical-axis floating wind pilot project. SeaTwirl and the Marine Energy Test Centre will test the prototype for five years near Lauplandsholmenoff. The project's progress stalled due to appeals from environmental and fishing groups, but Norwegian regulators' rejection of the appeals ensures SeaTwirl's S2X pilot can move forward without further challenges. Additionally, 3D-printed vertical wind turbines are growing, with several companies experimenting.

Going Bladeless

New innovation in wind turbines includes evolving designs beyond traditional blades. O-Wind has pioneered an omnidirectional design that simultaneously captures winds from all directions, a breakthrough that uniquely blends horizontal and vertical flows to cater to the chaotic wind patterns of urban areas. Available in varied sizes to suit diverse buildings, O-Wind turbines can connect to the grid or operate independently with battery units. From Xenecore, a design that incorporates I-beam ribs and microsphere structural foam amplifies power generation with its fan-shaped wind blades. And because the future needs wind technology that will work at relatively low wind speeds, the fastest-growing energy sector across the globe is bladeless wind energy. It leverages vortex shedding, a vorticity phenomenon, through a vertical cylinder affixed with an elastic rod. It oscillates within the wind's range and powers an alternator system to generate electricity. Prominent players include Vortex Bladeless, Tyer Wind, Agile Wind Power, Silent Wind, and Sway Turbine AS in Europe; Saphon Energy in Africa; and, Mag-Wind Vertical Axis Turbine, Atmocean, Enomad, and SheerWind in the US.

Airborne Wind Energy

Kitemill, a Norwegian enterprise, is pioneering the advancement of airborne wind energy, which involves attaching a turbine to a flying device, to revolutionize wind energy's effectiveness, versatility, and affordability. Its latest triumph, the KM2 system, is double the size of the KM1 prototype, has a 16-meter wingspan, and integrates four propellers for vertical takeoff. The system can generate an average power cycle of 100 kilowatts. In another promising collaboration, EnerKíte and Volkswagen embarked on a feasibility study to explore the potential of a mobile e-charging station. These innovative airborne wind turbines hold the promise of charging electric vehicles even in the remotest regions, reducing reliance on conventional power grids and enhancing green mobility.

NEW WIND

AI Wind Farms

Like most other industries, AI is also reshaping renewable energy. Israeli company vHive has introduced an advanced tool for wind turbine inspections, leveraging autonomous data collection and a novel digital twin platform. This innovation empowers wind farm operators to strategically digitize assets, elevate operational efficiency, and curtail output decline. UK's Cognitive Business is working with RWE's Robin Rigg offshore wind farm, delivering an AI-powered package that encompasses pattern recognition and production forecasting to ensure precise maintenance predictions and optimal performance. AI has also proven pivotal in the setup, upkeep, and enhancement of offshore wind farms. The Dhalion Inspection System by Perceptual Robotics is an interesting example with a fully autonomous solution for wind blade inspection, encompassing data acquisition, insights, and decision-making.

Dispatchable Wind Energy Production

As scientists find more ways to store wind energy, it will grow as a dispatchable electricity solution from which power grids can demand electricity based on market needs. One way to ensure such storage is by fusing hydrogen with the grid, like what's being done in the Netherlands. There, an alliance of prominent partners led by Shell is using hydrogen from offshore wind energy plants to stabilize the electricity grid, and aims to maintain 70% renewable electricity by 2030. The FlexH2 consortium, which includes TNO and other industry players, collaborates closely on joint research and pioneering technology development, expediting integration into the energy matrix.

AI helps to make Windfarms more efficient and maintain and optimize performance.

OTHER RENEWABLES

Geothermal

Unlike other renewables, geothermal energy represents a stable source of power that doesn't fluctuate with time of day or weather patterns. This energy can be harnessed by tapping into hot water and steam reservoirs beneath the Earth's crust. Once accessed, it can be used for direct heating or to generate electricity through geothermal power plants.

Supercritical Geothermal

Supercritical geothermal energy production requires going deeper into the Earth's crust than conventional geothermal, tapping into the extreme temperatures and pressures present there (in excess of 374 degrees Celsius and 221 bar, respectively). While containing enormous power generation potential, these conditions also present extreme technological challenges. Some of those may be alleviated by recent research, which has focused on tapping into supercritical geothermal fluids at sites adjacent to volcanic activity. At these sites, extreme temperatures and pressures can be found closer to the Earth's surface, greatly reducing the risk and investment required to utilize them. In Japan, the New Energy and Industrial Technology Development Organization has been experimenting in volcanic regions of Hokkaido. Meanwhile, new geothermal research and startups push the boundaries of existing technologies. Researchers are testing working fluids composed of supercritical carbon dioxide to transfer and pump heat back to the Earth's surface. Companies are developing new tools, like Thermochem's probe and logging tool rated to operate at temperatures up to 400 degrees Celsius. Barriers to development remain, however, mainly in the form of policy and international cooperation.

Using Geothermal for Energy Storage

Geothermal energy storage techniques hold energy in the form of increased temperature and pressure which is "pumped" into the earth and released as needed. Researchers and government agencies are looking closely at this option for storing sustainably generated energy in lieu of massive banks of electrical batteries, which require large quantities of rare earth elements and are not as efficient. Multiple research efforts have recently focused on using carbon dioxide as the storage medium, which has the added benefit of sequestering greenhouse gases. In the US, the National Renewable Energy Laboratory has begun efforts to identify high storage potential sites, and in Germany, the Karlsruhe Institute of Technology is evaluating how geothermal energy storage might be integrated into the existing grid.

Ocean Thermal Energy Conversion

Ocean thermal energy conversion generates power from the temperature difference that exists in ocean water. Because this difference is unaffected by weather and climate conditions, it represents a reliable source of sustainable energy. Furthermore, the seawater output from the process is usable in commercial applications such as fisheries, agriculture, and air conditioning. Japanese shipping company Mitsui O.S.K. Lines has announced a pilot program that would pump water from a depth of 600 meters at near-freezing temperatures to be used in a titanium heat exchanger; the process is expected to generate 1 megawatt of electric power by 2026.

Hydropower

Accounting for more than 15% of global electricity generation in 2022, hydropower continues to be the largest source of renewable power, contributing more than wind, solar, and biofuels combined. New opportunities for hydropower manifest in efficiency, storage, and small scale (but widespread) deployments.

Digitalization

Hydro plants have invested significantly in digital management for their equipment and systems, all with the aim of optimizing energy output and safety. Utilizing cloud computing and big data, operators hope to build machine learning models to guide automated decision-making in these complex environments. Given the risk involved with such a digital transformation, some operators have even

OTHER RENEWABLES

opted to create digital twins of their plants, enabling a safe environment for training the algorithms of the future. Spain has made significant investment so far, and officials plan to onboard 160 of its power plants to a digital management platform. China, too, is making strides, and officials have put all data from the Three Gorges Dam (the largest hydroelectric project in the world) into the cloud of Chinese company Huawei Cloud.

Small Scale Hydro

Small scale hydro projects are allowing energy suppliers across the globe to add more renewable energy generation to their portfolio without the need for massive, upfront investments of capital. In California, a pilot program led by startup Emrgy places small, modular turbines into irrigation canals to produce modest amounts of electricity, between 2 and 10 megawatts. The turbines operate in a manner that does not require damming the water. This, paired with the fact that all the canals used are pre-existing, means the impact to the local environment is minimal.

The European Union has also funded pilots for small scale hydro in sites across Central Asia. Though this region has the world's second largest potential for hydroelectric power, larger hydro developments there have been slow due to political, economical, and legal factors, such as water rights claims and concerns about environmental impact. Small scale hydro has the ability to simultaneously provide a significant source of power while avoiding many of those pitfalls.

Hydro as a Water Battery

Hydro storage, or "pumped storage," involves pumping water into uphill reservoirs when energy is cheap (or when renewables are operating) and then allowing that water to flow downhill and generate energy as needed. Recently, large investments in the field have been made across the globe. Switzerland just opened a 20-gigawatt-hour plant in the Swiss Alps that can transition from energy storage to energy generation in less than 10 minutes. In Utah, a $2.5 billion project broke ground that could provide 9GWh in capac-

ity by 2031. Spain started building a 200 megawatt plant in the Canary Islands. China, meanwhile, continues to lead the world in pumped storage capacity, with 51 gigawatts currently in operation and more planned to come.

New Turbine Design

Companies continue to innovate on the design of hydro turbines. Turbulent, a Belgian engineering company, has developed an underwater vortex turbine capable of operating in remote locations. With low maintenance and water flow requirements, it is ideal for rural communities with simple irrigation. Similarly, Emrgy is working on hydrokinetic turbines that can be dropped into canals and other low pressure, low flow environments. Voith Hydro in Germany made adjustments to the centuries-old Pelton Wheel design, which allows its turbines to operate in a horizontal configuration, as opposed to vertical. More injectors can be utilized in its operation, increasing its overall output. Additionally, companies such as Natel are work-

ing to minimize the environmental impact of hydropower. Its latest turbine implements a curved blade design aiming to drastically reduce the rate of marine life fatality for creatures passing through.

CLEAN FUELS

Hydrogen

Hydrogen fuel technology has been around since the 1950s, and for the past 75 years, it has served as the main propulsion source for spacefaring vehicles. Recent developments, including updated designs for hydrogen fuel cells, have reignited conversations of using the fuel source closer to home. In particular, "green hydrogen" (hydrogen fuel produced using renewable energy), has been viewed as an emissions-free alternative for long distance naval, aerial, and ground transportation. However, issues of economics and scale remain.

Reducing the Cost of Hydrogen Production

Researchers are making progress in reducing the cost of green hydrogen generation. Many of these efforts focus on improving the materials coating the electrodes used to extract pure hydrogen from water. Separate research teams, both in Korea, have perfected protective titanium oxide coatings that reduce corrosion in the electrodes and have experimented with using cheaper iron nitride as a coating alternatives. An Oxford-based team has pursued similar coating-based improvements, focusing on alkaline electrolyzers. Meanwhile, American company TFP Hydrogen has announced plans to scale up its electrolyzer coating capacity threefold over the next year, up to 600 megawatts annually. Canada-based Loopflow has developed a new fuel cell design with a unique geometry and flow field properties that increase the stability of internal conditions and efficiency.

New Base Materials

Currently, hydrogen is typically extracted from treated freshwater. As issues of water scarcity continue to grow, hydrogen power companies have sought to harness alternative sources. Efforts in Guam, the Netherlands, and Australia have focused on using seawater, both treated and untreated, for hydrogen generation. A large EU pilot program will explore using wastewater as a base material. Other efforts are looking into an even more direct method: accessing "geologic hydrogen," or sources of pure hydrogen trapped in the earth, in gaseous or other forms.

Biofuels

Biofuels encompass any fuel made or derived from organic matter—typically corn, sugar cane, or soy. These fuels include ethanol, biodiesel, and biogas. While biofuels represent an alternative to fossil fuels, concerns have arisen over the amount of farmland needed to provide significant amounts of energy and the impact large scale operations might have on food systems.

Biofuels From Hemp

Hemp represents a unique opportunity for biofuels. It can be turned into multiple types of fuel (e.g., ethanol, methanol, biodiesel) and boasts one of the highest energy densities of any land-grown crop. However, the plant's association with cannabis is often seen as hindering widespread adoption (industrial hemp has only a fraction of the THC associated with recreational marijuana). A bipartisan bill in the US hopes to change that by deregulating hemp and legally decoupling it from cannabis. Meanwhile, researchers at Texas A&M are breeding new

Hemp's high energy density makes it a great source for biofuel.

CLEAN FUELS

strains of hemp that are both suitable for the state's dryer climates and fall within THC compliant ranges.

Biofuels From Algae

Through photosynthesis, certain kinds of algae can produce biofuel. As added benefits, they absorb carbon dioxide and grow organically. In spite of this, scaling biofuel extraction from algae is slow and expensive. Researchers in Brazil have conducted experiments with microalgae in which they "stress" the culture to induce it to make more lipids, the key component in biofuel production. Other experiments have focused on genetically modifying algae to optimize their efficiency and survivability characteristics. United Airlines has invested $5 million in biofuel startup Viridos, which focuses on producing sustainable aviation fuel from algae in seawater.

Syngas From the Sun

Synthesis gas, or syngas, is a mixture of hydrogen and carbon monoxide that can be used as fuel and in the production of methanol. Researchers at the University of Cambridge have devised a solar-powered reactor that extracts carbon dioxide from industrial waste, or even from the atmosphere, and converts it into syngas using what they describe as "artificial leaves." By infusing ceria (a common material used in syngas production) with a nickel catalyst, researchers at the University of Florida have demonstrated the ability to create syngas at lower temperatures—700 degrees Celsius instead of 1,000 degrees—a reduction that provides economic benefit to producers.

Scientists are exposing algae to stressors to increase lipid production, the key component for biofuels.

FOSSIL FUEL INNOVATION

Rededication of Contaminated Land

Abandoned coal mines could be the solution to warming homes in Europe, where homes across the continent are sitting on top of old mines filled with warm water. The water gets warmer the deeper it goes and can be brought up through boreholes, run through heat pumps and extractors to increase the temperature even more, and then sent through heating networks to warm homes. Once the water is used, it can be redirected back into the mines where it is heated again. The UK is currently exploring this project beginning with 12 preliminary boreholes in Glasgow.

Reducing the Carbon Footprint of Fossil Fuels
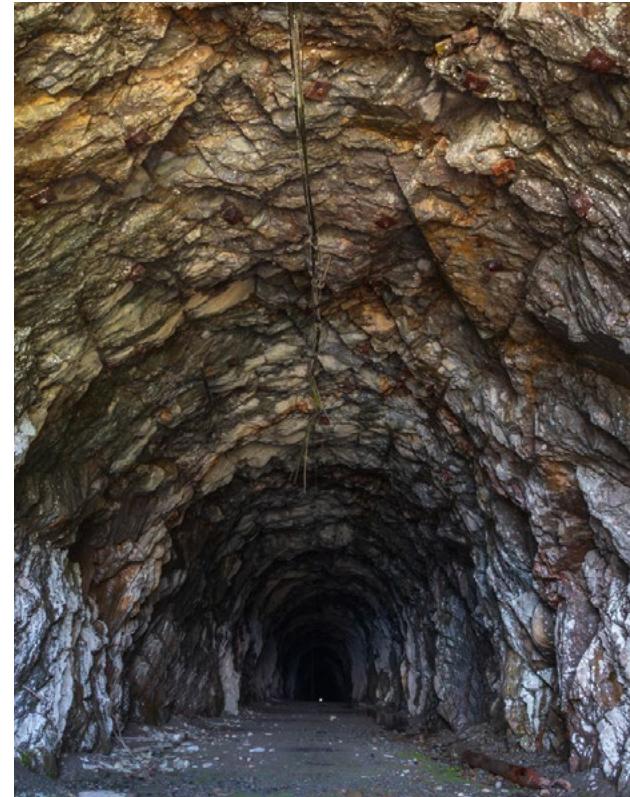
In many countries, regulators and researchers are attempting new ways to reduce fossil fuels' impact on the climate crisis. The US Environment Protection Agency has proposed new regulations on limits for pollutants from American coal and gas power plants, forcing facilities to track and report emissions. Korean companies have successfully operated a gas turbine with a cleaner 60% hydrogen blend fuel. Japan is turning coal into "clean hydrogen" through the Hydrogen Energy Supply Chain project, which uses carbon capture and storage technology and has attracted $2.35 billion in investment. Botswana is working with South African-based Sasol's extensive coal resources to produce synthetic fuels to support Europe's energy crisis. And in the UK, Net Zero Teesside Power is on track to be the world's first commercial-scale gas-fired power station with carbon capture. The project will drive the UK government toward its decarbonization goals and produce enough electricity to power 1.3 million homes per year.

Methane Emissions Reductions

Methane, a potent greenhouse gas, plays a major role in trapping heat in the Earth's atmosphere. Recognizing its importance as a driver of climate change, regulators and scientists are turning their attention to finding ways to reduce methane emissions. The Inflation Reduction Act contains the first ever greenhouse gas fee in the US. Oil and gas companies will pay a fee if they emit more than 25,000 tons of carbon dioxide equivalent per year into the atmosphere, thus spurring innovations in methane emission monitoring to avoid the fee. A team of Princeton University researchers has developed extremely agile drones with remote-sensing lasers to detect gas leaks up to 25 times smaller than can be detected using traditional methods. The drones only require a small mirror and laser and can be outfitted to measure other gases such as carbon dioxide and ammonia as well as methane. Swiss-based Distran, an innovator in ultrasonic camera technology to detect gas leaks, has recently closed $8.3 million in funding to diversify their products and tap into new markets to expand the safety of industrial plants and reduce their environmental impact.

Abandoned coal mines could support warming homes in Europe.

NEW NUCLEAR

Fusion

Long considered the "holy grail of energy production," nuclear fusion technology would allow humans to emulate the atomic process that powers the stars. Most experimental fusion reactors today seek to fuse hydrogen atoms into helium, the same reaction our own sun has been conducting for billions of years. This reaction creates substantial amounts of energy in the form of extremely fast moving atomic particles, which can be converted to heat and then used to power generators. The only byproducts are heavier (potentially useful) elements and trace amounts of radiation at harmless levels. Given the cosmic abundance of hydrogen, nuclear fusion would provide a virtually limitless source of energy.

Fusion Momentum

Following the Lawrence Livermore National Laboratory's landmark achievement in 2022, when researchers created the first human-controlled, net-positive energy-producing fusion reaction, conversations around the technology have reignited, capturing the attention of both private and public sectors. Lawrence Livermore has already repeated—and improved upon—its initial experiment. Startups funded by tech millionaires have begun to enter the field. However, large obstacles remain—namely the massive amount of investment and lengthy timelines needed to develop the technology into something meaningful. Even the most generous estimates place large scale nuclear fusion over 30 years away, a sobering reality check given the planet's immediate need for sustainable sources of energy.

Privately led Fusion Projects

The US Department of Energy injected capital into a growing ecosystem of private fusion projects, by distributing $46 million in funding to eight companies. Incumbent players, such as TAE Technologies, continue to iterate and produce new reactor designs while newer ventures, such as the Sam Altman-backed Helion, aim to bring a Silicon Valley-esque sense of disruption to the industry by targeting small scale reactors.

German startup Proxima Fusion has raised $8.6 million to pursue a twisting, new reactor design, one drastically different from the widely used, toroidal tokamak design.

Molten Salt Reactors

Although the idea of using molten salt as a coolant for nuclear fission reactors has been around since the 1950s, it was more or less abandoned as most commercialized nuclear installations opted for water cooling instead. Now, companies and researchers are revisiting the concept, seeing it as a way to increase efficiency (by making it easier to extract thermal energy), generate additional fissile material (which can then be used in subsequent reactions), and reduce radioactive waste. Researchers at MIT plan to explore the practicality of molten salt reactors while companies such as Kairos Power and TerraPower are developing commercial models.

Laser-Driven Fusion

Laser-driven fusion, also known as "inertial confinement fusion," is a means of triggering fusion reactions by firing high energy laser volleys at small pellets of deuterium and tritium to increase temperature and pressure. Following the landmark net positive fusion reaction from Lawrence Livermore in 2022, which utilized laser-driven ignition techniques, additional funding is finding its way into the space. Marvel Fusion, a German startup, plans to build a $150 million high-power laser and fusion research facility at Colorado State University. With an expected completion date of 2026, the facility will be the most technologically capable research site for laser fusion energy and high-energy density physics.
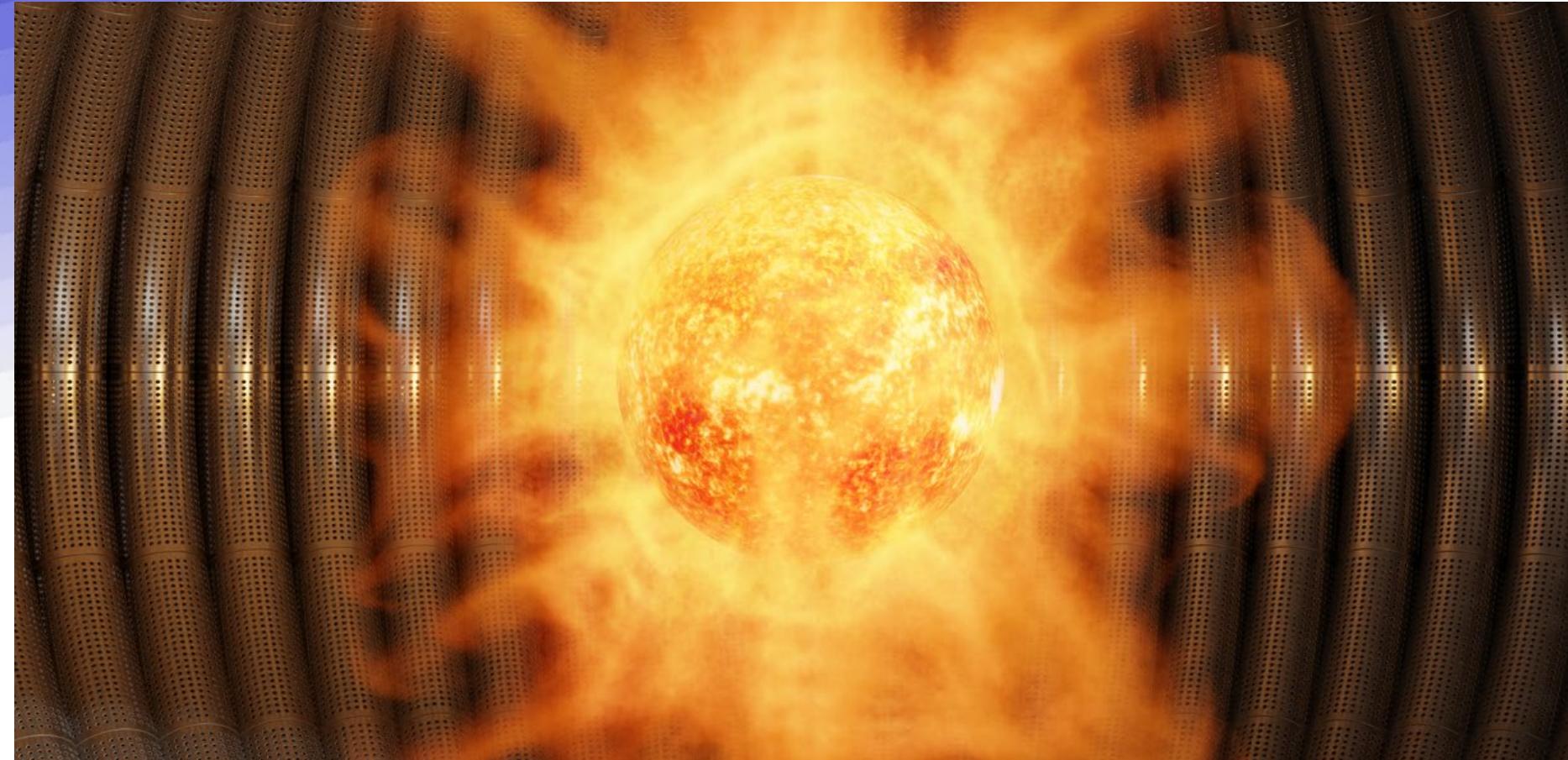
Small Modular Reactors

Early in 2023, the US Nuclear Regulatory Commission certified the first design for a small modular reactor capable of nuclear fission, meaning utilities can now select it when building a new power plant. This could represent a major opportunity for new nuclear proj-

NEW NUCLEAR

ects, especially as a complementary solution to less reliable emissions-free generation, such as solar and wind. Conventional nuclear power plants are bespoke, heavily site-dependent, and must be constructed on-site. These small modular reactors can be factory made and integrate much more easily into existing grids. The approved design is rated at 50 megawatt output though the company behind it, Nuscale, is hoping to get higher capacity models approved soon.

Extraordinary sums of money continue to flow into nuclear fusion, however, timing for scaling remains elusive.

EMERGING FORMS OF ENERGY PRODUCTION

Energy From Thin Air

New technology is being developed to create clean energy from the materials in the Earth's atmosphere. At KU Leuven University, Belgian researchers have created solar panels that produce hydrogen from the water vapor in the atmosphere and convert it into electricity via a hydrogen fuel cell. The hydrogen panels will be on the market through the startup Solhyd; they can produce up to 250 liters of hydrogen a day, and the gas can be stored in a tank to use later. At the University of Massachusetts Amherst, researchers have developed a device that harnesses the same technology as lightning, by using electricity generated from water droplets passing through the generator's porous material. The "air generator," or Air-gen, can make clean electricity almost anywhere and runs only on ambient humidity, providing a completely sustainable energy source. And in Australia, an enzyme has been found by scientists that can do something similar, by turning air into energy. The enzyme, commonly found in soil, can create electrical currents using low amounts of hydrogen in the atmosphere.

Wave Power

Wave power, or using wave energy to create electricity, is a growing industry that is expected to increase 4.7% to $30.44 million by 2030. In Australia, Wave Swell Energy has done this with floating devices. The company uses the concept of oscillating water columns to power its turbines: As waves push water up and down into a hole at the bottom of the floating devices, the air in the space is pushed out of the device and in turn spins a turbine that creates electricity. Closer to shore, Eco Wave Power uses "floaters" that can be attached to existing man-made structures. These floaters rise and fall, moving a piston, accumulator, and hydraulic motor to create power in a generator. The company's floaters were added at the Port of Los Angeles and are currently being scaled up; they could generate up to 69% of California's electricity production if fully scaled. And on the support side, AWS Ocean Energy, who is currently working with Wave Energy Scotland, is providing technology and services for those in the marine energy industry. The company services oilfield infrastructure, aquaculture, and renewable energy resources to maritime communities.

Tidal Turbines

Underwater, companies are turning the movements of the tide into electricity. Scotland's MeyGen tidal power project, an array of four underwater turbines about 66 feet below the ocean's surface, has generated 50 gigawatt hours of electricity as of February 2023, the first of its kind to do so. This is roughly equivalent to the annual electricity consumption of 4,700 US homes. Off the coast of Eastport, Maine, Ocean Renewable Power Co. is beginning to test turbine generators that could be commercially viable. The turbine will have a 12 month test period, and then the company plans to implement a full scale four turbine system further along the coast. There are also many other tidal energy startups that have secured substantial funding, showing a trend in attention returning to tidal power, including Sustainable Marine Energy, which raised $11.3 million; Orbital Marine Power, which raised $11.4 million; and Verdant Power, which raised $8.73 million.

Mimicking Photosynthesis

Researchers at the University of Cambridge have made a groundbreaking discovery in the photosynthesis process that could change how we generate renewable energy and clean fuel. Photosynthesis powers a majority of life on Earth, and it was previously believed that the chemicals that can extract electrons occurred later in the photosynthesis process. However, researchers discovered it takes place much earlier and pathways exist to move electrons that were previously unknown. This new discovery opens up new ways of using power and the ability to mimic photosynthesis to create clean fuels from water and sunlight. This ability to regulate photosynthesis could also increase crops' ability to tolerate sunlight in a world facing climate change.

ALTERNATIVES TO MINERALS AND RARE EARTHS

Local Sourcing

Chinese mines account for about 60% of the global supply of germanium and 80% of gallium—minerals used in everything from smartphones to electric car batteries. Last year, in what appeared to be retaliation for American technology trade limitations, China enacted heavy export restrictions on these materials, sending many nations scrambling to find alternate sources. These actions have raised concerns that restrictions on rare earths, which China also dominates (70% of global production), might not be far behind. As a result, in recent years Australia, Canada, the US, and the EU have all invested in finding domestic sources of rare earths. For example, mining company Northern Minerals has invested $80 million in the exploration of the Browns Range in Western Australia and plans to use the site to add dysprosium and terbium to its current offerings of neodymium and praseodymium. The demand for rare earths has also kicked off a heated debate over deep sea mining and which countries can lay claim to the rich resources on the ocean floor; however, international law does not yet permit such large scale operations, and the environmental impact is not well understood.

Alternative Materials

As another strategy to decrease dependency on rare earths, researchers have begun developing alternative materials to replace them. A number of Japanese companies claim to have developed valid substitutes in the magnet space. Proterial has produced a "high performance ferrite magnet" made from iron that claims to replace neodymium magnets in electric vehicle motors. Automotive parts manufacturer Denso has purported a similar breakthrough, making a magnet using iron and nickel. Others have developed a design using iron and samarium. It is perhaps not surprising that these companies are all based in Japan; that nation was the first to feel the brunt of China's rare earth trade restrictions in 2010.

Rare Earth Avoidance

Certain manufacturers have attempted to strengthen their supply chains by reducing, or completely eradicating, their need for rare earths. Vitesco Technologies, an electric vehicle parts manufacturer, has developed an "externally excited synchronous machine" (ESM) motor design that can replace the permanent magnet synchronous motor (PSM) design that currently dominates the EV market. In high-performance vehicles, which often require larger or more powerful magnets, the ESM design offers an economic advantage over the PSM design due to its reduced dependence on costly rare earth elements. Tesla has likewise announced a powertrain design that reduces the company's dependence on rare earths, citing economic, stability, and environmental motivations.

Countries are looking to diversify their sources for rare earth and minerals.

SCENARIOS
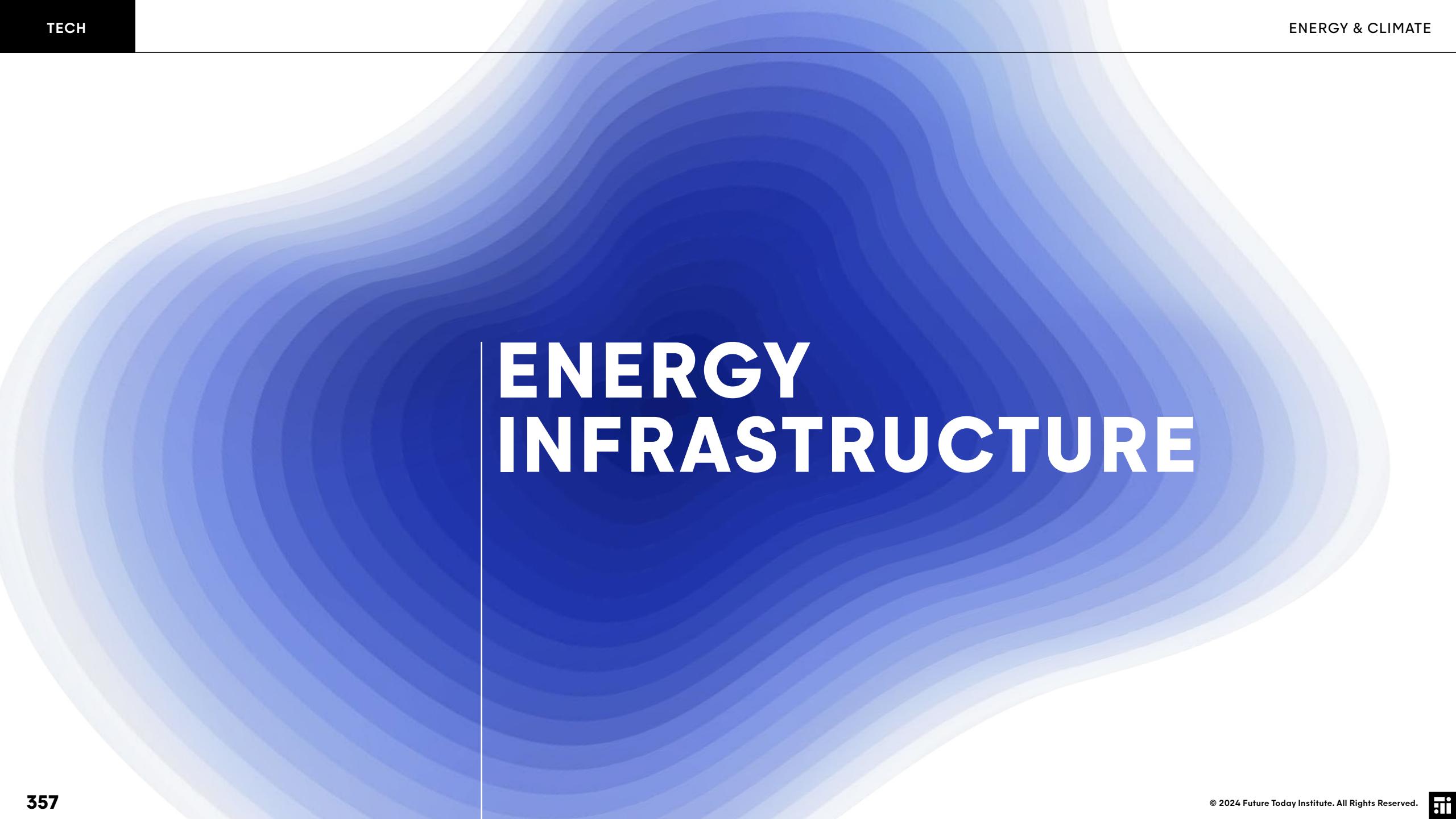
What If the World Runs on Thermal Energy?

In 2035, Thermal Symphony Networks power our world with renewable energy. This technology's dual capabilities are leveraging temperature contrast for clean electricity generation and provide heating and cooling with no moving parts. Initially designed to enhance urban energy production and efficiency where wind and solar were not as easily integrated, Thermal Symphony Networks quickly transcended their purpose: sidewalks paved with thermoelectric tiles captured footfall heat to power nearby buildings, and architectural facades lined with thermoelectric panels balanced indoor temperatures while generating electricity.

As the networks gained traction, industries experienced a paradigm shift. Farmers established "Energy Orchards," where temperature-controlled environments enclosed by thermal tiles optimized crop growth while generating power. Global maritime transport saw the implementation of thermoelectric ship coatings, converting temperature differences between ocean water and cargo into energy. Electric vehicles equipped with thermoelectric systems harnessed the heat generated during braking to recharge their batteries, extending their range. Airports showcased runways embedded with thermoelectric materials, converting the temperature contrast between asphalt and air into additional power for terminals.

The benefits of Thermal Symphony Networks even extend underwater: The technology's heat exchange mechanisms promote coral reef health, reversing the damage caused by rising sea temperatures.

ENERGY INFRASTRUCTURE

ENERGY STORAGE

TPV Batteries

Given the inherent intermittency of wind and solar power, electricity generated from these sources needs a more dependable energy storage system that would work irrespective of weather patterns. TPV batteries are one such solution to bottle and store renewable energy.

Experiments are being conducted across the world to find storage alternatives that are affordable, eco-friendly, and scalable. In Italy, Enel X and Magaldi Group are building a 13-megawatt-hour thermal energy storage using patented fluidized sand bed technology. This stores heat that is then used to release steam at 120-400 degrees Celsius. In Spain, researchers created a battery that uses renewable power to melt metals like silicon, storing latent heat that powers a thermophotovoltaic generator to produce electricity. In the US, Antora Energy has innovated on TPV (thermophotovoltaic) technology to convert carbon block light back into electricity, offering cost-effective and emissions-free heat and power innovation. Using wind and solar

energy to heat solid carbon blocks over 1,500 degrees Celsius, Antora can also provide its technology to industrial processes requiring high levels of heat. In line with the idea of ensuring high-temperature stability, a novel nanophotonic material—embodying structural variations on a scale comparable to the wavelength of light—has shown promising potential for efficient production and control of thermal radiation. Scientists at the Lawrence Berkeley National Lab and Scripps Research are also exploring new ways to handle high energy levels in extreme conditions.

Iron Batteries

With its abundance, iron continues to be a reliable source for energy storage, and companies are devising new ways to use iron batteries to do this on a large scale. Form Energy, a startup, will supply iron-air batteries to Xcel Energy's 1-gigawatt-hour project that is slated for operation in 2025. Lithium-iron batteries are also gaining popularity. While their environmental and geopolitical significance has always been central to growth,

technology has also bridged the performance gap with materials like nickel and cobalt. Our Next Energy, a startup, is launching production of lithium iron phosphate (LFP) batteries in Michigan. It plans to expand via a new $1.6 billion plant that will supply 200,000 electric vehicles with LFP batteries by 2027. Among the larger companies, Ford has chosen to license LFP battery technology from China-based CATL to provide more cost-effective options for customers, while General Motors is also exploring using LFPs to cut costs. Delta has introduced an outdoor lithium-iron battery system meticulously tailored for megawatt-level energy storage applications, addressing the pressing requirements for grid ancillary services, solar plus storage, and backup power assurance.

Solid State Batteries

Introducing a groundbreaking leap in making battery-powered flight a reality, NASA's Solid-state Architecture Batteries for Enhanced Rechargeability and Safety (SABERS) team has unveiled a sulfur selenium pro-

totype battery with a high energy density of 500 watt-hours per kilogram. With a storage capacity twice that of traditional lithium-ion batteries, these batteries offer the rapid discharge capabilities necessary to be used in aircraft. Toyota has set its sights on launching solid-state batteries in its mass-produced EVs by 2027. The company has discovered a new way to simplify the production of solid-state batteries and enable shorter charge times with an extended driving range. Nio, an EV company, in an update to its user manuals, has introduced a new 150 kilowatt-hour semi-solid state battery pack alongside its existing battery lineup. The Nio ES6 model in China will incorporate these solid-state batteries. Factorial Energy, a solid-state battery developer, has forged collaborative partnerships with Hyundai, Kia, and Mercedes-Benz to implement its vision of scaling solid-state technology by 2026. The company has expanded beyond the US to South Korea, Japan, and Germany. Furthermore, the realm of 3D-printed solid-state batteries holds transformative potential, promising enhanced energy storage solutions for various applications.

ENERGY STORAGE

Gravitational Energy Storage

In exploring innovative energy storage solutions, gravitational energy is gaining traction as a way to create kinetic energy. Swiss company Energy Vault is nearing completion of gravity battery installations in the US and China that are projected to produce 36 and 100 megawatts, respectively. Australian startup Green Gravity has joined forces with mining contractor RUC to fast-track the adoption of its gravitational energy storage technology. Their technology moves ultra-heavy weights in mine shafts to turn turbines and create electricity. Meanwhile, UK-based Gravitricity is set to initiate pilot demonstrations of its gravity energy storage systems in India, with plans for broader deployment in the future.

Flow Batteries

An emerging idea, flow batteries leverage the flow of special liquids to generate electric current. Pacific Northwest National Laboratory is using β-cyclodextrin, a basic sugar extracted from starch, in a flow battery formulation. This innovative sugar can be synthesized within laboratory settings, offering a sustainable and environmentally friendly alternative to currently used materials. The US Army collaborated with Lockheed Martin to test a new flow battery that aims to store energy for a longer duration and at scale. Called GridStar Flow, this rechargeable flow battery will use engineered electrolytes to charge itself. Energy Dome, an Italian startup, is using "CO2 Battery" to store energy. With fresh funding secured, the tech company plans to operationalize two standard 20MW-200MWh frames by the close of 2024.

Capacitors

Supercapacitors store and release electrochemical energy using a flow of electrons between two conductive plates separated by an electrolyte. Skeleton Technologies, an Estonian company working on energy storage technology, has introduced the SuperBattery, which combines the attributes of supercapacitors and batteries. This innovation boasts an extraordinary charging speed 100 times faster than lithium-ion batteries, coupled with an impressive life cycle of 50,000 cycles and higher safety standards. Additionally, a research group at Japan's Osaka Metropolitan University has developed a highly deformable solid electrolyte. Being touted as the world's first bulk-type all-solid-state capacitor, this capacitor can function at high current densities and promises higher efficiency and performance.

Compressed Air Storage (CAES)

These systems use high pressure air to spin turbines and generate electricity. Currently, only two commercial CAES plants exist globally: the Huntorf plant in Germany and the McIntosh plant in Alabama. They utilize diabatic processes, where off-peak electricity compresses air for storage, later mixing it with natural gas for combustion during peak demand. Hydrostor, a Toronto-based developer, has devised an innovative plan scheduled for completion in 2028; it involves drilling three deep shafts that are about 100 yards high and as long as two football fields. The company will use excess renewable energy to compress air into them, later releasing high-pressure air to generate power. Stanford University researchers have developed a model to gauge the required compressed air storage for deep decarbonization of power systems. Testing their model on California's energy grid, the group has highlighted the cost-effectiveness of compressed air storage on a dollars-per-kilowatt-hour basis as compared with other sources of energy.

ENERGY TRANSPORT

UHV Power Lines

Ultra high voltage (UHV) power lines can efficiently carry electricity over long distances with minimal loss, enabling energy optimization across vast areas. While China leads UHV use, other countries and alliances across the world are exploring projects to use this technology. One example is the North Sea Wind Power Hub, a collaboration from nine European countries to generate 120 gigawatts of wind power by 2030 and 300GW by 2050. The project aims to support Europe's transition to a low-carbon energy system through wind power and uses UHV transmission lines to interconnect the electricity grids of these different countries. Beyond Europe, India, Brazil, and Russia are also exploring UHV implementation.

Superconductors

Superconductors can unlock high-speed energy transportation without resistive loss. In a feat first hailed as groundbreaking, scientists at the University of Rochester seemed to have crafted a superconductor from nitro-gen-doped lutetium hydride that was able to transmit electricity at low temperatures and pressure. However, the experiment couldn't be replicated. If successful, superconductors could scale technologies such as levitating high-speed trains and make long-distance energy transport (including wind and solar energy) a feasible alternative. The SCARLET initiative, supported by the EU, unites 15 partners from seven countries to develop superconducting cables, enhancing cost-effective and efficient power transmission of renewable energy along with hydrogen in the same pipeline. The project took off in September 2022 at the Institute for Advanced Sustainability Studies in Potsdam, Germany. Focused on further improving long-distance energy transmission through superconductors, SuperNode, an Irish renewables technology company, has partnered with CERN. CERN, a leader in superconductivity research, will bring its cryogenic and vacuum expertise to analyze sample materials and subsystems.

Ultra high voltage power lines are needed to effectively distribute energy from renewable resources.

THE GRID
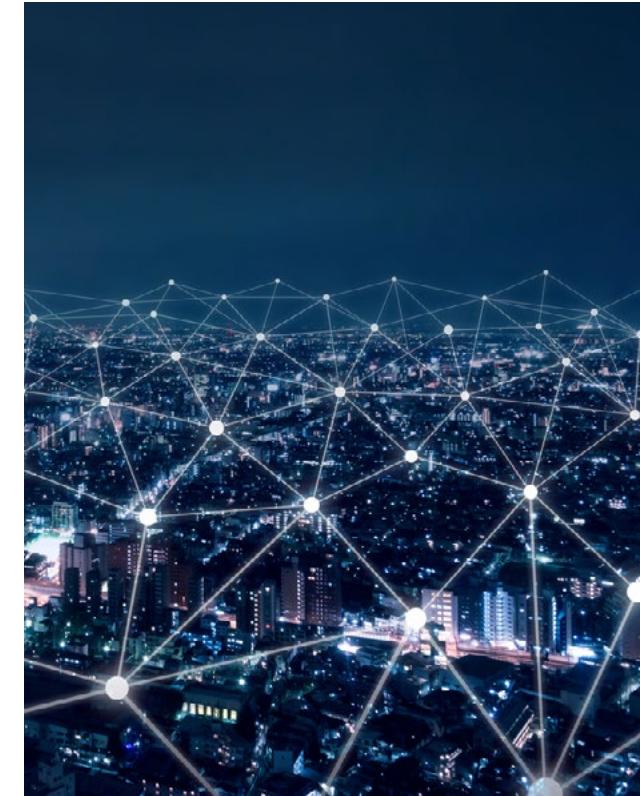
Dynamic Line Rating (DLR) Systems

With climate change, energy grids across the globe are under more pressure, and grid operators are increasingly using new technologies like dynamic line rating (DLR) systems to enhance the grid. Using sensors, the technology delivers real-time information on factors affecting grid performance, such as wind speed and temperature. In the US, PPL Corp. has been sending hourly forecasts to PJM Interconnection, the regional transmission organization, since 2022. UK's National Grid has collaborated with LineVision, the only company specializing in noncontact power line monitoring, to deploy sensors and a DLR platform. This advancement aims to optimize grid performance by accurately assessing power line conditions. In Australia, the Renewable Energy Agency granted Infravision $732,000 to support the development, testing, and trial of the "Next Generation Line Monitoring System," thus enhancing electrical transmission grid performance.

Balancing the Flow of Power Within the Grid

Balancing the flow of power within the grid is important to ensure that electricity demand is met in real time with supply. The University of Applied Sciences of Western Switzerland has pioneered an optimization algorithm that can identify the coordinates of electric current surges in power grids without knowing the grid's overall structure, thus reducing outage costs. Another grid-enhancing technology is the Advanced Power Flow Control, where devices can rapidly push or pull power from over or under-utilized lines within a transmission network. The National Grid Electricity Distribution, a project aimed at decarbonization, has launched the Planning Regional Infrastructure in a Digital Environment (PRIDE) project to bring together key stakeholders on a unified platform to analyze data and make decisions on energy systems. Collaborating with the West Midlands Combined Authority and Advanced Infrastructure, PRIDE explores the potential of digital twins to understand the regional energy demands and enable decision-making based on this data. The project explicitly highlights the importance of local and regional decision-making in decarbonization. In Ireland, the transmission system operator EirGrid has partnered with Smart Wires to implement advanced power flow control devices that automate and optimize the grid and increase the use of new renewable energy.

As the percentage of renewable energy in the grid increases, we need smart technologies to ensure stable distribution and supply.

EMISSIONS REMOVAL

CARBON CAPTURE & STORAGE

Natural CSS

One method of naturally removing carbon dioxide from the atmosphere is the mass farming of seaweed, which sucks the gas from the air. However, a new study has revealed that the amount of seaweed needed to make an impact (a million square kilometers) may be too much for turning this solution into a widespread strategy for combatting climate change. Mosses are showing substantial promise after a new study revealed that moss-covered soil can store 6.43 billion metric tons more carbon in the soil beneath it than soil can on its own. The total potential amount of carbon dioxide that could be stored by mosses is about six times the annual global emissions caused by activities such as deforestation, urbanization, and mining. A French startup is trying to grow genetically modified house plants to better filter the air around them. In Georgia, foresters have begun planting acres of the first genetically engineered trees, which are designed to grow faster and capture more carbon than their traditional counterparts.

Direct Air Capture

Directly capturing carbon dioxide from the atmosphere is expensive and requires a lot of energy. But because the industry is so visible and young, it's attracting new innovators such as ex-Tesla Director Douglas Chan who founded Climeworks with the goal of being able to remove carbon dioxide by the gigaton by 2050. Climeworks has announced plans to scale up its US operations after successfully running several European plants. California-based HolyGrail uses electrically powered modular scrubbers to remove carbon dioxide from the atmosphere and turn it into mineralized cubes, which can be stacked on top of each other above ground. Global Thermostat is at the forefront of carbon removal technology and has unveiled its new Direct Air Capture machine—one of their largest yet, the unit can remove 1,000 tons a year. The company provides customers with the main components and associated design plans of the machine, so that the actual building and implementation can be done by a construction company of their choice. Jap-

anese utility company Tokyo Gas is investing in Global Thermostat in pursuit of its net-zero goal for decarbonization.

CO2 Storage

Denmark made history last March with Project Greensand, which captured carbon dioxide at a site in Belgium, transported the liquid gas to the Danish North Sea and then injected it into the seabed at a depth of about 1,800 meters. Project Greensand is also working with Danish company Resen Waves, which created buoys that generate power through the ocean waves and can be used to monitor the seabed-injected carbon dioxide, detect leaks, and also work as Wi-Fi hotspots at sea. The project 44.01, involving partners Abu Dhabi National Oil Co., Fujairah Natural Resources Corp., and Abu Dhabi Future Energy Co., eliminates carbon dioxide by turning it into a solid rock formation. It is the first mineralization project to use seawater and the first carbon-negative project by a Middle Eastern energy company.

Seaweed captures carbon, but it's questionable if there is enough to make an impact.

CARBON CAPTURE & STORAGE

CCS-as-a-Service

As the demand for carbon capture and sequestration services increases, CCS-as-a-service business models continue to spread. EnQuest, a UK oil and gas company, secured carbon storage licenses from North Sea Transition Authority in the UK's first-ever carbon sequestration licenses. The company plans to ship carbon dioxide in liquid form to the Sullom Voe Terminal in Shetland, a 1,000-acre future carbon storage hub, before sending it via an existing pipeline for injection and permanent offshore storage. Due to the flexibility of shipping carbon dioxide in liquid form, this should make it easier for EnQuest to service more isolated carbon emitters that may not otherwise have access to this type of storage. Ørsted's Asnæs biomass power station and Northern Lights JV have signed a carbon dioxide Transport and Services Agreement to store 430,000 tons per year of biogenic carbon dioxide from two Danish power plants. This is a major milestone for both the European commercial CCS market and Northern Lights JV. Charm Industrial, a company that turns agricultural remnants into bio-oil, will be getting $53 million from carbon-removal credits to turn its agricultural waste into oil that can lock up carbon dioxide for a million years and be stored underground.

First carbon storage licenses have been secured for the North Sea.

CARBON UTILIZATION

Carbon-Based Food

Traditional farming methods cause mass damage to our environment in the forms of habitat loss and deforestation—using up land, drying up water sources, and releasing a third of all greenhouse gas emissions. Solar Foods wants to change that by making food directly from carbon dioxide. The company is aiming to start production in 2024 in the first commercial-scale factory in Finland. Solar Foods' technology involves bacteria that use hydrogen as their energy source; it creates a yellow powder that is 70% protein and can replace animal sourced proteins, such as eggs in noodles and pasta. The process will use 200 times less land, 600 times less water, and emit up to 200 times less carbon dioxide than traditional protein sources.

Diamonds

Diamonds come with a shady history that can frequently involve corrupt governments and exploitative working conditions. Aether is providing a completely conflict-free option by making diamonds out of atmospheric carbon dioxide. The US company captures carbon dioxide from the atmosphere with a thermochemical process, purifies it, adds green hydrogen to create atmospheric methane, and then puts it in specialized chambers where diamond material can begin to form. The diamond material is cut and polished with traditional methods and can be placed in a variety of jewelry from engagement rings to earrings. The diamonds themselves are carbon-negative.

Hair Care, Soap, and Laundry Detergent

Theoretically, carbon can be sequestered in household products, and CleanCO2 has found a way to do that. The company captures carbon dioxide from building heating systems using a device called CarbinX and processes it into potassium carbonate (a non-toxic pearl ash). This pearl ash is used in the soap formula to create a sudsy lather when used, and ends up in everyday products such as hair care, soaps, and laundry detergents. Founded in Alberta, Canada, the company has now expanded to the US and Japan and is deploying its CarbinX units globally.

Chemical Production

The research team at RWTH Aachen has developed a new chemical reaction that uses carbon dioxide in the creation of a chemical compound called aromatic carboxylic acids. This compound has a variety of uses from herbicides to plastics—but most importantly, it is used in medicine. In the pharmaceutical industry, a common type of aromatic carboxylic acid is salicylic acid, which is used in aspirin. The RWTH Aachen team's discovery not only opens the door to many new industries but creates the opportunity to utilize waste carbon dioxide and more sustainably turn it into a chemical compound that can be used globally.

US Company Aether is manufacturing carbon-negative diamonds.

CARBON TRACKING

Funding Influx

The rapidly growing climate technology industry is facing an overall mass increase in funding initiatives. Microsoft's Climate Innovation Fund has pledged to distribute $1 billion by 2024, and Amazon's Climate Pledge Fund has pledged $2 billion; these projects vary from concrete that can trap atmospheric carbon to portable batteries that could replace diesel-burning generators. Venture capitalists are investing more than $140 million in startups, resulting in unprecedented funds for climate technology: Persefoni raised $114 million, Watershed raised $85 million, SINAI raised $36 million, and Sphera raised $21 million.

Tracking Platforms

Large, established companies are seeing the value in carbon tracking software, and many are creating their own or expanding their services to cover carbon data. SAP's Sustainability Data Exchange will allow companies to securely exchange sustainability data in a standardized format with suppliers and partners in order to quickly reduce carbon emissions in supply chains. EY has released the beta version of EY OpsChain ESG on its EY Blockchain SaaS Platform; the product will provide verifiable and accurate carbon dioxide emissions information and allow clearer tracking of an enterprise's carbon footprint, providing companies and regulators with a transparent, trusted platform for carbon emission and credit traceability. Microsoft has introduced the Microsoft Cloud for Sustainability to help organizations more easily track their emissions and is continuing to add capabilities and updates to the platform, including a way to track indirect carbon emissions that frequently go untracked. Amazon Web Services has customizable solutions that use AI, machine learning, data analytics, and the Internet of Things to capture, analyze, and manage a company's sustainability data.

Government Investment and Regulation

The US General Services Administration's Green Proving Ground program is on a mission to decarbonize federal buildings, and nZero, a carbon management and accounting platform, is at the forefront. The company will track federal buildings' electricity usage in real time in an effort to make them net-zero. The agency, along with the US Department of Energy, will invest $30 million toward this net-zero buildings goal. The EU enacted its Corporate Sustainability Reporting Directive, which requires companies to report scope 3 (indirect emissions) and double materiality—the implications on the company's financial value as well as impact to the environment and world overall. This directive also includes stricter rules on corporation's social and environmental disclosures.

Individual Consumer Tracking

A variety of new tools are encouraging individual consumers to consider carbon footprint when making decisions. Reewild, a UK company, has created an app for consumers, food brands, and retailers to see the carbon footprint of a variety of food products. They simply need to scan an item's barcode while using the app, which is still in its beta phase. While it is only in the UK, the company plans to scale the app to the EU and the US. American Express and MasterCard have introduced an emissions tracker for consumers to see how their actions, habits, and spending behaviors impact their personal carbon footprint based on purchases. Google Flights and Uber have also rolled out emissions data tools for individual consumer tracking. Australian bank Westpac developed a tool with Cogo, a carbon footprint management fintech, that will provide customers with personalized carbon emissions trackers based on their spending. The bank hopes the transparency will help close the knowledge gaps that are preventing individuals from making more sustainable decisions. Consumers can also track their waste using Bintracker, a software company, that uses QR codes to track waste streams down to individual tenants and then analyzes and reports on trends and data down to the source, day, and composition.

SCENARIOS

SCENARIO YEAR 2050

What If CO2 Is the Foundation for Consumer Products?

In the year 2050, consumer goods conglomerates such as Walmart and Amazon have utilized the scaling of nanotechnology to not only effectively integrate carbon capture, utilization, and storage into their operations but also to provide the delivery of personalized products at scale. A network of specialized nanobots, which the companies release into the atmosphere en masse, attract and bind carbon dioxide molecules from the atmosphere and transport them to central processing units. Within these central processing units, the carbon dioxide is converted into versatile carbon-based raw materials that can be tailored to various applications. The processing units receive customer orders within a 30-mile radius in real time and are equipped with hundreds of 3D printers, as well as a wide range of other raw materials and chemical components. Based on the order of each customer, the carbon dioxide raw materials are integrated into the appropriate material concoction and printed into everything from highly specific building components to carbon-based foods and intricate consumer goods.

EMISSIONS REDUCTIONS

GREEN PROCESSES

CONSTRUCTION

Carbon Neutral or Negative Building Materials

From plant-based building materials to more sustainable concrete, companies are experimenting with new ways to construct buildings. Plantd, a sustainable building materials company, creates strong, moisture resistant carbon-negative building materials from fast-growing perennial grass. With $10 million from recent funding, Plantd's products will provide a direct substitute for traditional home construction materials and lock in 80% of the atmospheric carbon dioxide the plants captured in the field. Elsewhere, a new type of engineered wood that traps carbon dioxide, strengthens the material for use in construction—the natural material goes through a process that makes it carbon dioxide-sorbent and stronger than its more natural state. The company MAA'VA is creating eco-concrete, a sustainable carbon negative construction material, by transforming nonplastic and plastic waste. This eco-concrete is adaptable to both conventional and 3D printing con-struction, which can create housing for one-tenth the cost and half the waste.

3D Printed Houses

The use of 3D printing methods to build housing is expanding rapidly, and the use of natural materials is expanding with it thanks to designers Ronald Rael and Virginia San Fratello. They created Potterware, a browser-based application that allows for 3D designing without the need to understand 3D modeling software; it also allows the use of natural materials such as clay, salt, mud, sawdust, or Chardonnay grape skins in designing and printing. In Europe, the continent's largest 3D printed building is being built in Heidelberg, Germany, to house a data center. The construction is expected to take 140 working hours of robots applying layers of concrete, instead of dozens of human workers. In Round Top, Texas, the seasonal tourist town is about to see five vacation rental homes that are being called the world's first "near-zero-carbon, 3D-printed homes." These homes are the result of a partnership between Eco Material Technologies—a cement alternatives company—and Hive 3D—an automated construction company. The result will be a building process which will emit 92% fewer emissions and cost 30%-40% less than a traditional construction project of the same size.

Companies are increasingly using materials such as clay and sawdust for the 3D printing of houses.

GREEN PROCESSES

HEAVY INDUSTRIES *(Steel, Chemicals)*

Steel and Iron

Steel production is responsible for 7%-9% of the world's total carbon emissions, and investments in green steel companies are ramping up. While more resources are coming into the industry than product rolling out, that may soon change. Hydrogen is playing a role in advancing the steel refinement process: The first large-scale green steel production plant is being built by H2 Green Steel in Sweden, aiming to cut greenhouse gas emissions by 95% during the production process. Using hydrogen technology instead of blast furnaces, the plant plans to start shipping its first commercial batches of steel by 2025. Across Europe, companies like France's GravitHy, Germany's Thyssenkrupp, and Spain's ArcelorMittal are constructing hydrogen-based plants. Another advancement to soon enter the steel industry is the use of Molten Oxide Electrolysis, a process that uses electricity to separate oxygen from iron ore, leaving oxygen instead of carbon dioxide as a byproduct. Boston Metal hopes to bring this technology to the steel industry within the next two to three years. The US has a goal of a net-zero steel sector and is on its way to that, claiming to have the cleanest global emissions footprint due to the steel it produces being roughly 70% made from recycled scrap.

Chemicals

As US regulators move to restrict two forever chemicals in drinking water, companies are experimenting with the technology to do it. Also known by their proper name of perfluoroalkyl and polyfluoroalkyl substances, PFAS are in everything from waterproof clothing to dental floss and can cause cancer, liver damage, fertility problems and more. While the removal of these chemicals with conventional filtering techniques is nearly infeasible and can be costly, researchers at Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB have found a way to use plasma-based technology to reduce the chemical's molecular chains and remove them at a low cost. Johns Hopkins University's Applied Physics Laboratory has applied "nanowhiskers," aluminum-based membranes that attract PFAS contaminants and are designed with a cost-effective coating. Northwestern University chemists have found a process that uses low temperatures and common, inexpensive reagents can remove two major types of PFAS chemicals and leave them as benign products—this powerful solution from a simple technique could be the key to removing the chemicals at a large scale. University of British Columbia has also discovered a scalable solution in the form of a filter that uses a unique absorbing material to trap and hold the chemicals.

A variety of research institutions have come up with promising filtering systems to remove forever chemicals from our ecosystem.

GREEN PROCESSES

AGRICULTURE

Plants Without Plants

Novella is creating plants without the whole plant by growing botanical ingredients with necessary macronutrients through nutrient cultivation—no plant needed. This will help address the increasing demand for necessary macronutrients, help overcome supply chain disruptions, expand plant's life cycles, and reduce climate impact. While typically a majority of a plant could be discarded, just to get to the specific bioactive compounds, this avoids that waste. This process costs less, wastes less, and provides more safe, natural botanicals without chemical additives than current processes, rising to meet the global demand.

Fertilizer Innovation

New developments in fertilizer technology are helping ensure stronger, healthier plants—and experimenting with new uses for waste material. EnGeniousAg has received a grant of $1 million to create soil nitrogen sensors that are low cost, provide instant readouts, and can help farmers measure nitrogen levels in their crops in a matter of seconds. Along the same lines, startup Phospholutions recently won the Africa AgTech Startup Showcase by showing fertilizer efficiency can be increased to maintain crop yield by reducing the phosphorus in it by 50%. Tracegrow Oy, a Finnish cleantech startup set to expand operations, is creating certified organic fertilizer from alkaline batteries. Taking the used batteries, extracting micronutrients needed by crops, and placing them in fertilizer has not only enhanced crop productivity but also reduced carbon dioxide emissions compared to traditional fertilizers.

CRISPR Edited Crops

CRISPR is a technique that allows for the editing (such as addition or deletion) of an organism's DNA—it's a different technology from what's used in genetically modified organisms, or GMOs. While many international governments have strict GMO regulations, they've responded differently to crops that have genes edited with CRISPR. Under a new law, the UK will allow for gene-edited crops to be planted, Canada will not regulate crops that have gone through changes, and the European Commission is considering next to no regulation for genetically modified crops. This is a dramatic change from the European Commission's previous stance, which put in place an intense and expensive approval process for such crops. But regulators see a lot of possibilities in gene-edited crops, including saving many from famine due to climate change and high demand for food. Already, gene editing is beginning to help expand the yield and temperature resistance of staple foods like rice and cowpeas to meet demand.

Waste

Organic waste used to be something to be disposed of, but now opportunities are arising to utilize this material in new ways. Wasted, a Vermont-based company, created portable toilets that transport the human waste it captures to nutrient recovery facilities that process the waste and turn it into fertilizer. Mill Industries is doing something similar but with household waste. The company offers a food waste bin and service for $33 a month where the bin will collect, grind, and dehydrate the organic matter. The company then notifies the owner when the material, in the consistency of coffee grounds, needs to be shipped to a processing facility to be turned into chicken feed.

DIGITAL EMISSIONS

Reducing Carbon Emissions

The increased interest in machine learning has also raised questions about the carbon footprint of developing and using such technology. Google published the "4Ms"—Model, Machine, Mechanization, and Map Optimization—four practices the company believes can reduce emissions involved in machine learning by 1,000 times and energy by 100 times. Model refers to selecting model archetypes for machine learning that can produce quality while reducing computation by 3-10 times. Machine refers to using processors specifically for machine learning that can improve energy efficiency by 2-5 times. Mechanization refers to using cloud computing in data centers customized for that type of processing which use higher efficiency servers resulting in less emissions. Finally, Map Optimization refers to allowing customers to select locations with the cleanest energy, which will increase demand and thus the growth of such green data centers, reducing carbon footprint by 5-10 times.

Measuring Emissions

With Google employing the "4Ms," the rest of the tech giants are also stepping up to address emissions from devices. Taken together, all devices globally linked via the internet have a similar electric consumption to that of the entire country of France. Amazon, Meta, Microsoft, Samsung, and Sky have teamed up with the Carbon Trust to set an industry standard for measuring and cutting carbon emissions from their devices while they are being used by consumers. The group aims to find a baseline to report energy efficiency improvements, apply technology to reduce energy use of connected devices, and drive toward its ultimate goal of industry-wide net zero emissions. Researchers from the Loughborough Business School have also created a new tool that helps businesses determine the carbon footprint of their data and allows them to create data strategies that are environmentally sustainable.

Google hopes to reduce emissions caused by machine learning by 1000 times through its 4M practice.

RECYCLING

AI Waste-Sorting Robots

AI's accuracy is being used to improve the sorting of recycling in order to cut costs. After a two year trial, Google's AI-driven recycling-sorting robots have showcased a high degree of accuracy. The reinforcement learning system used on the robots in the study increased accuracy by providing feedback through rewards and penalties, and the AI improved the robots' decisions to maximize the amount of rewards received. A UK start-up, Recycleye, has developed an AI-based waste-sorting robot, which recently won $17 million in funding. The robot uses "vision" to sort waste into plastics, aluminum, cardboard, and paper with greater accuracy than humans. Recycleye also announced a partnership with Il Solco, an Italian company that plans to use the AI-based waste-sorting robots in that country.

Food

Organic waste in landfills eventually builds up, breaks down, and produces methane, a powerful greenhouse gas. The company Divert recently received $1 billion to increase the use of microbes to break down this organic waste; this process is called anaerobic digestion, and it could help reduce the 40% of methane released from landfills by avoiding sending the waste there in the first place. Another method is biohydrogen production, which turns waste into a renewable, clean energy source. Many processes can be used in this production but all use microorganisms to break down organic waste materials and create hydrogen gas. Water is the only byproduct.

Plastic

The startup Norbite uses the greater wax moth (Galleria mellonella), which naturally digests plastic, to get rid of the material. It also uses the moth's larvae for a variety of products, such as protein for animal feed, and the moth's feces for biofertilizer. Researchers at Leipzig University have discovered an enzyme that can degrade lightweight PET plastic packaging. The enzyme is able to compost this plastic type at a higher efficiency than previously seen in other enzymes, including those discovered in Japan in 2012 that were dubbed "plastic eaters." Enzyme PHL7 was discovered to be the fastest enzyme to break down PET plastic by 90% in 16 hours, and the byproduct of this enzyme can be rebuilt into new plastic.

The greater wax moth digests plastic, the feces can be used for biofertilizer.

GREEN MATERIALS

Cross-Laminated Timber

Cross-Laminated Timber is a minimum of three layers of timber glued together with grains that cross. Typically, timber can become structurally unsound if enough force is applied along its grain, but with cross-laminated timber this is far less of an issue. The material is lightweight, has increased strength, and has even shown to have a higher resilience to seismic forces than traditional timber. But the product is also a way to use smaller trees, the types of trees that are usually removed from forests in order to make them less prone to fire. Mercer Mass Timber, a company that specializes in CLT, is preparing for an increase in demand due to building codes in Oregon, Washington, and California now classifying it as a new class of construction. OPAL Architecture has created a unique, all-electric home using cross-laminated timber and wood-fiberboard insulation to achieve the goal of creating a home with the lowest-possible carbon output. The Maine-based company cited the new timbers as the only material that would work due to its structural capacity, dimensional stability, and carbon-storing capacity. Besides being strong, the cross-laminated timber panels provided such air sealing that heating or cooling the interior space would only require one-third of the typical amount of energy.

Mycelium

Mycelium, a natural fiber from mushrooms, can be used as a plastic alternative in items such as textiles, building materials, packaging, and health care products. Completely biodegradable, this material can be used to replace plastics such as polyester, building polymers, concrete, packing materials, and threaded wound covers. Mushroom Inc. is focused on finding new ways to use mycelium hyphae to reduce toxic plastics and waste while creating more carbon-neutral products. Researchers at Newcastle University have been able to grow construction materials using mycocrete, a composite paste of mycelium. Using a knitted framework, the composite is fed and allowed to grow until it reaches the needed density, and then it is dried out and used as an eco-friendly alternative to plastic, timber, or foam.

Mushroom Plastic

New research has focused on the fungus Fomes fomentarius and the way its multiple layers could soon replace a multitude of plastic products. The mushroom has three layers: a hard outer layer, a soft middle layer, and an inner layer similar to the texture of wood. These multiple layers can potentially be used in many different products, from windshield impact-resistant coating using the hard outer layer to leather-like materials using the soft middle layer. Led by a scientist from VTT Technical Research Centre of Finland, a research team was able to create prototype headphones using the mushroom's structure. The applications for the different parts of this mushroom are vast, and the researchers' hope is that this will soon be the more sustainable alternative to many plastics.

Self-Healing Materials

There's a lot of historical precedent in this field—ancient Roman concrete structures have long been known to be self-healing. The structures contain lime clasts, which were originally believed to be an unfortunate byproduct. But reevaluations of the durability of Roman concrete structures have concluded that this was an intentional choice: As cracks formed in concrete, the liquid that reached these lime clasts would reactivate calcium sources and create calcium carbonate to refill the cracks and keep the structure sound. Now, researchers are experimenting with engineering different materials to similarly heal themselves. While performing experiments on how cracks form and spread, researchers at New Mexico's Sandia National Laboratories saw cracks in copper and platinum spontaneously heal. The team believes this self-healing could be engineered into metals to react this way to stress and cracks. At North Carolina State University, researchers have created self-healing composite material that allows its structures to be repaired in place without having to be removed from service. There is also research underway to create self-healing plastic at the University of Michigan, and scientists have successfully created self-healing solar panels for use in outer space using the mineral perovskite.
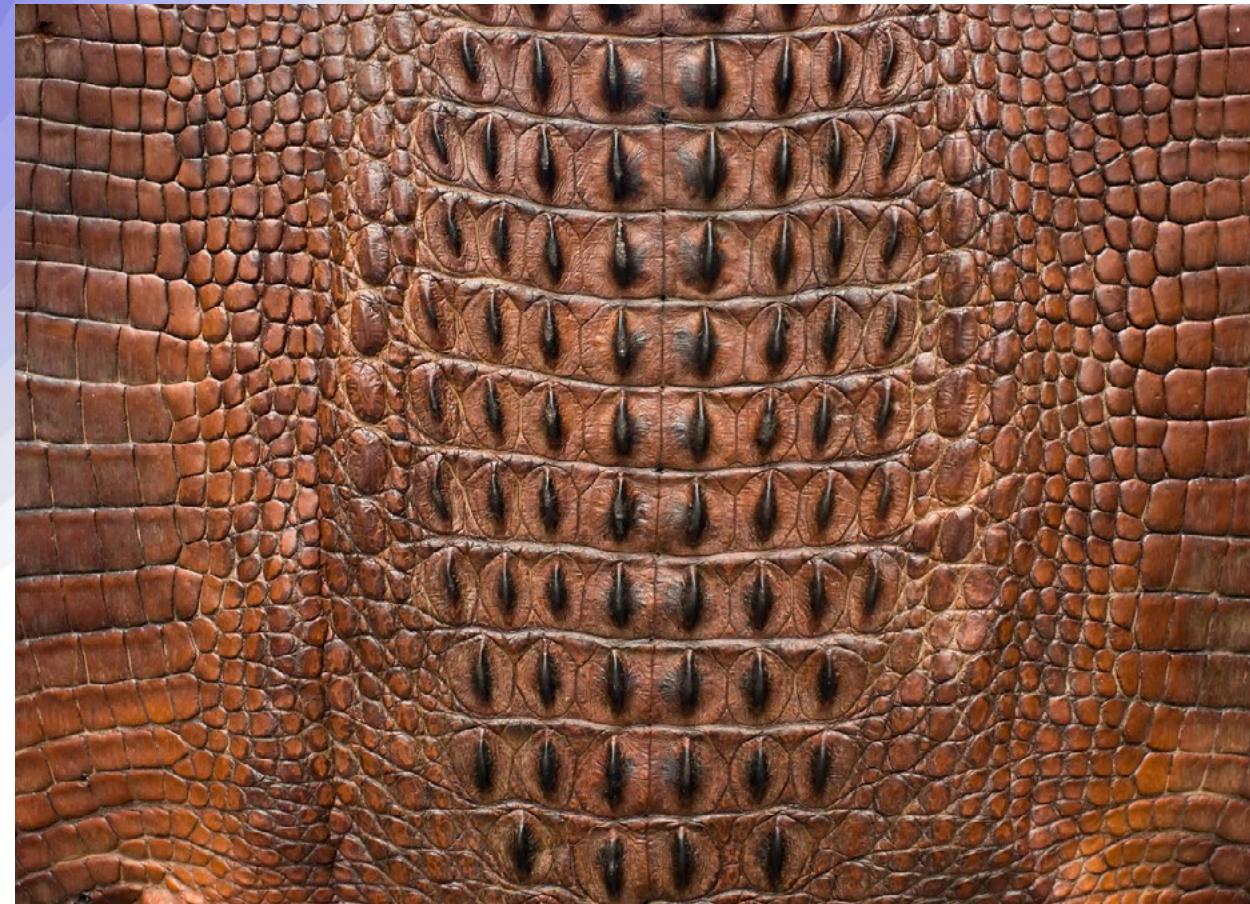
GREEN MATERIALS

Lab Grown Leather

Vegan leather is becoming more popular as a sustainable alternative to traditional leather, but the material typically uses polyurethane which is toxic. The material innovation company Von Holzhausen has created Liquidplant, a top coating for textiles that can help make vegan leather more durable without using harmful chemicals. Other companies are experimenting with using different materials for vegan leather, including TômTex's work with shrimp shells. Using shrimp shells ground into flakes and then turned into a liquid, the company is creating vegan leather for wallets, mimicking leather and its durability without any petrochemicals. ProjectEx, a Singapore lab-grown exotic leather producer, is aiming to raise $1 million in order to create a sustainable, cruelty free exotic leather for the luxury market. The first leathers are expected within two years of completed funding with plans of scaling afterwards. The project is a partnership between designer Adrian Furstenburg and deep-tech startup Cellivate Technologies. And 3D Bio-Tissues has successfully grown leather "skin" in a lab without any need for animals. The company believes that lab-grown leather technology could be market-ready in five years.

A Singapore project aims to create cruelty free exotic leather.

GREEN TRANSPORT

Micromobility

Micromobility refers to compact personal transportation, like bicycles, skates, and scooters, and companies are making it easier for people to use these devices for greener daily commutes. French-based startup AtmosGear has created the first set of electric inline skates; they have a range of 20 miles on a fully charged battery that is stored in a fanny pack, bringing back the Rollerblading aesthetic. The skates connect to the battery via a wire that travels down the back of the leg and allows the wearer to go up to 20 mph. Another startup increasing micromobility options is electric bike and scooter company Yulu. Its app shows rentable scooters' availability in real time. Lime is doing something similar by focusing on electric scooters and bike-sharing. The California startup is a leader in the space, and is operating in 250 cities across 30 countries. It has backing from Uber and other investors that could help this startup expand even more.

Cars

Until now, charging electric vehicles (EV) has been the primary way of keeping them on the road. But startup Ample has a battery-swap system that can swap out an empty EV battery for a fresh one in 5 minutes, far less than batteries take to charge. With many other companies pursuing the idea, battery swapping could bring the ease of a gas station to EVs on the road. For combustion cars, there may be a new alternative that can keep them on the road in the EU despite the 2035 deadline to phase out polluting vehicles—running on e-fuels. E-fuels are synthetic fuels made from hydrogen and carbon dioxide, and can be processed in today's combustion engines. While e-fuels do still emit carbon dioxide when they are burned, the amount taken out of the atmosphere to produce the fuel offsets the amount that is created when the fuel is burnt. Luxury car company Porsche has also created its own synthetic fuel made of carbon dioxide and water that can be used in its current cars. The Porsche e-fuel is among the many seeing the potential in the fuel market.

Heavy Trucks

Truck platooning, where one driver and truck are connected to a convoy of autonomous trucks via a network and drive close behind each other, could ease passenger traffic on motorways. This use of autonomous vehicles would increase fuel efficiency through lesser air resistance and would save costs for long-haul trucking. This technology is in the trial phase in several countries and could soon see the road, with an expected cost savings of up to 45% compared to today's trucks and drivers. Wireless charging is another technology that so far has been mainly explored within freight transport. Electreon, a company specializing in charging electrical vehicles in motion, has an agreement with France to equip a portion of a southwest Paris motorway with its Wireless Electric Road System. Currently pursuing similar projects in Sweden, Germany, Italy, and the US, the company says its product will increase power transfer capacity and include real-time monitoring software for all types and classes of vehicles. However, for now the focus remains on commercial EV fleets.

Tesla's purchase of Wiferion, a German-based wireless charging company, further signals that the technology is prone to enter passenger driving sooner rather than later.

Trains

Sun-Ways is making trains green by going beyond the locomotives themselves. The company is using the spaces between railway tracks to lay out solar panels "like carpet." Sun-Ways estimates that a terawatt-hour of solar energy per year could be produced from the national rail network in Switzerland, equivalent to 2% of the country's total energy consumption. Meanwhile, Polish company Nevomo is exploring hyperloop-inspired technology for the potential future of rail freight. Nevomo uses MagRail technology, magnetic propulsion that could be a traction enhancer. While capacity, reliability, and frequency are more important factors than speed for rail freight, this technology could have a revolutionary impact on the industry—especially considering it would allow trains to work on both the company's MagRail system and traditional tracks. Nevomo also signed a deal with the French rail

GREEN TRANSPORT

operator SNCF to evaluate if its technology can increase train efficiency and capacity.

Air

When it comes to air travel, any part, no matter how small, can make a big difference. SWING has its focus on the front flaps of planes, creating them out of thermoplastic polymers and decreasing their weight by about 20%. While this is just a first step with this type of material, SWING hopes that eventually the polymers could be used to craft entire aircrafts, reducing emissions by up to 20%. Autonomous aircrafts could first see their application with unmanned cargo planes. Dronamics, a UK-based company, released of one of the first unmanned cargo aircrafts at the end of 2023. The aircraft takes less time to operate, saves money, and emits less carbon dioxide than traditional cargo freight, catering to underserved areas and multiple industries. Startup ZeroAvia has completed a record test flight in a 19-seat aircraft half powered by hydrogen fuel cells. With investment from commercial airlines, it's now looking to move into commercial tests.

Ocean

With shipping being such a large part of global trade, many ships are looking to reduce their carbon footprint due to new carbon efficiency regulations. To do this, many are looking to wind and developing wind propulsion technologies to decrease fuel usage. US food company Cargill announced it will install two folding sails in its bulk carrier's deck, and container shipping group Maersk installed two 30 meter-high rotor sails on one of its tanker ships. In an effort to make fuel cleaner, a viscosity meter has been developed to test the oil used in ship engines, which is typically full of impurities. The ultrasound device is meant to improve shipboard monitoring and lower the cost.

Tankers might soon be equipped with sails to make them more fuel efficient.

ENVIRONMENTAL MANIPULATION

EARTH

Rewilding: Animals/Nature

Countries across the world are initiating rewilding efforts, an ecological restoration approach that involves restoring natural ecosystems and habitats by reintroducing native plant and animal species. A NASA-supported initiative in Idaho uses remote sensing data to forecast the streams that could support beavers and monitor the biodiversity shift once beaver populations are introduced. In the Netherlands, Marker Wadden is a 1,300-hectare archipelago built with the mud and sand of the lake that now houses diverse plants, fish, insects, and breeding birds. Meanwhile, Scotland, aiming to be the world's first rewilded nation, has created countrywide wild lands and natural corridors. This rebuilding of ecosystems in Scotland has been enabled by land ownership laws that allow a few to own most of the land. (In contrast, in Ireland, where land ownership is limited to several acres, natural woodlands make up only 1% of the island, compared to 80% long ago.) In Mexico, tequila company Tromba strives to rewild and reforest land damaged by blue agave over-cultivation, targeting

1,000 hectares in a decade. Citizen-driven initiatives are also growing. Designer Kiki Grammatopoulos has introduced "Rewild the Run," featuring bristly running shoe outsoles that aid plant and seed dispersion in cities. Agricultural rewilding has also grown, combining rewilding with agriculture to maintain food self-sufficiency and promote sustainable and ethical high-quality meat production.

Bioengineering

Scientists predict that almost a quarter of all species on Earth are at risk of being lost within the next few decades. De-extinction is a scientific method to bring back and resurrect extinct or close to extinct species. Organizations like nonprofit Revive & Restore and for-profit Colossal Bioscience, are pioneering these efforts. For instance, Colossal is using gene editing to revive the dodo bird, while Revive is focused on the passenger pigeon. In both cases, the newly created animal will be a hybrid and not a replica of the predecessor, qualifying for patent protection and thus producing

immense financial prospects. At the National-Black-Footed Ferret Conservation Center in Colorado, Dr. Della Garelle of the US Fish and Wildlife Service is spearheading the revival of America's endangered ferrets. Over 4,000 genetically similar ferrets have been released into the wild since 1991; this helps ecosystem restoration, but the limited gene pool makes them vulnerable to disease. To maximize breeding success, biologist Robyn Bortner picks and matches ferrets based on their genes. In this context, the San Diego Frozen Zoo is essential, as it leads the de-extinction field with the world's largest living animal cell bank, enabling DNA collection and storage for future restoration efforts.

For more on rewilding in cities and municipalities, please see our the Rewilding trend in our Built Environment book.

The black footed ferret is one of the species that is being rewilded in the US.

SKY

Geoengineering

Geoengineering refers to environmental manipulation—manipulation of Earth's resources including oceans, rivers, soil, and atmosphere. Although it's in an early stage of development, geoengineering technology is already being commercialized, leading to criticism from scientists across the world. The regulation around it is also mired in conflict, with different countries adopting contrasting approaches. In Mexico, the company Make Sunsets is sending gas-filled balloons into the atmosphere and selling "cooling credits" without much scientific validation. The lack of regulation is allowing such companies to function despite low credibility. On the other hand, the European Union is grappling with the complexities of this issue and considering potential regulations. Meanwhile, in China, geoengineering is being considered as a tool for hybrid warfare strategy. Especially in the realm of regional geopolitics, China could amplify its gray zone capabilities and use weather modification for military purposes, obstructing river water flow, and even creating artificial islands.

Solar Geoengineering

Still in a nascent stage, solar geoengineering is very controversial. It theorizes that by reflecting more sunlight into space, global warming can be controlled, but countries and international institutions are grappling with how to regulate the space. The US government, recognizing the need for further research, has proposed a study of risks associated with deploying solar geoengineering techniques. The EU, while formally disqualifying solar geoengineering as a climate solution, also recognizes the need to deepen understanding of the implications associated with the technology. More recently, the United Nations convened a panel of climate experts to deliberate international regulation of the stratosphere, stressing the need to manage risks associated with spraying aerosols to reflect sunlight. In the UK, a first-of-its-kind solar geoengineering test flight has been conducted, showcasing ongoing exploration of the concept. As a part of it, scientists launched a high-altitude weather balloon into the stratosphere that is low-cost, controllable and recoverable. Keep-ing up with innovation, MIT scientists have proposed a unique approach to use a fleet of "space bubbles" to reflect sunlight from space instead of injecting particles into the atmosphere, potentially reducing harmful effects. Meanwhile, startups are considering iron particle spraying above the ocean to combat climate change by breaking down methane, a natural phenomenon that may have influenced ice ages. However, scientists stress that more fundamental research is needed before considering large-scale implementations.

Cloud Seeding

Cloud seeding is a decades-old weather modification technique that enhances precipitation by dispersing specialized particles into the atmosphere. With increased focus on climate change, new and improved cloud seeding techniques are being developed and embraced across the world, including in the US, China, Russia, and parts of the Middle East. India recently made strides in this field by embarking on its first cloud-seeding initiative where an aircraft released chemical powder to stimulate rain in clouds. Experimentation continues in other countries as well with diverse seeding materials. The United Arab Emirates, at the forefront of innovation, has been using cloud seeding for more than two decades, leading to a 25% annual increase in optimal precipitation. Researchers are now employing nanotechnology and harnessing algorithms to optimize cloud seeding conditions, and they are exploring the use of drones to amplify the efforts. In Texas, Dan Martin from the Department of Agriculture's Agricultural Research Service is investigating the use of electrically charged particles to trigger cloud condensation. In an experiment, an aircraft with tanks of water released a spray of electrically-charged water particles into the cloud to see its effect on precipitation. The United Kingdom, meanwhile, is pioneering the use of electrical pulses as a potential seeding technique.

OCEAN

Microplastics

Innovative ideas are surfacing in the battle against microplastic pollution, offering hope for a cleaner ocean. One such initiative, GoJelly, harnesses the mucus produced by jellyfish species to craft filters that effectively trap plastic particles from wastewater, preventing their entry into the ocean. The project is innovatively using the growing jellyfish population to curb microplastics. Another breakthrough comes in the form of sound wave technology. Recent research reveals that pulsing sound waves can efficiently dislodge microplastics from the ocean's depth including tiny small specks that may otherwise be easy to miss. The team experimented with a prototype comprising sturdy 8 millimeter steel tubes and a powerful transducer. With the sound waves, even the small particles vibrated and accumulated.

Living Breakwater

Living Breakwater is an innovative approach to coastal protection and ecological restoration that utilizes nature-based solutions. A remarkable milestone has been achieved in the Port of Rotterdam, where 17 Reefy Reef-Blocks have been successfully installed in the river Meuse. The project experiments with innovative nature-based wave barriers to safeguard the shores from the impact of large ship waves while preserving and restoring regional biodiversity. By reviving the intertidal environment, the living breakwater provides a vital sanctuary for migratory fish species like sturgeons and European eels, facilitating their journey between the Atlantic Ocean and major European rivers. In New York, the "Living Breakwaters" project off the south shore of Staten Island aims to protect coastal communities and promote ecological restoration by creating habitats for marine life and fostering biodiversity. Encompassing a series of eight in-water structures stretching 2,400 linear feet, the project was initially slated for completion by the end of 2024 but is currently ahead of schedule.

Ocean Chemistry

Ocean chemistry is a multidisciplinary field that delves into the chemical processes and composition of Earth's biggest bodies of water. Researchers at University of California, Santa Barbara have recently been exploring a proposal to enhance ocean alkalinity for accelerated carbon sequestration. By enriching the ocean with minerals and increasing alkalinity, they aim to stimulate geologic processes that efficiently remove carbon dioxide from the atmosphere. Promisingly, their study reveals that crucial plankton groups in the marine food chain respond positively to this treatment, encouraging further research in this climate change intervention. Despite the positive outlook, concerns have increased about using minerals such as basalt to increase the alkalinity of seawater: These methods may disrupt nutrient cycles and affect marine ecosystems. Acknowledging the significance of marine geoengineering in climate change mitigation, the Australian Labor government has taken a proactive step by introducing a bill to regulate "marine geoengineering" activities. The proposed legislation seeks to govern and control interventions in the ocean environment. Listed marine geoengineering activities would require permits, ensuring proper oversight and safeguarding against ecological consequences.

Gene Editing

Gene editing coral refers to the scientific practice of using advanced genetic engineering techniques to modify the DNA of corals. The goal is to introduce specific changes to its genetic code, which can enhance its resilience to environmental stressors, such as rising sea temperatures, ocean acidification, and disease. Scientists, including Carnegie Science's Amanda Tinoco, have employed genome editing tools to unlock a pivotal discovery in coral development. Their research highlights the significance of a specific gene known as $SLC4_{\gamma}$, which is essential for the growth of skeletons in young coral colonies. This gene, exclusive to stony corals, encodes a protein responsible for transporting bicarbonate across cellular membranes, a crucial process in coral skeleton formation. This breakthrough offers opportunities for further research into coral resilience and conservation strategies.

SCENARIOS

What If a Sunshield Leads to a New World Order?

As the effects of climate change became more dire and governing bodies noticed that conventional climate mitigation efforts would not be sufficient to prevent catastrophic impacts to their populations, the most impacted nations launched "Project Celestial Shield." The core of this initiative involved launching an array of solar reflectors into space, positioned to intercept a portion of the sun's energy and redirect it away from Earth to counter rising global temperatures. Initially celebrated as a revolutionary solution, Project Celestial Shield successfully attenuated the planet's temperature rise. However, with the reduced influx of solar energy, regions that once relied on specific temperature patterns faced abrupt shifts in climate. Agricultural cycles even in thriving regions have been disrupted, leading to decreased crop yields and global food shortages. Ecosystems accustomed to specific temperature ranges experienced upheaval, resulting in mass migration of species and a ripple effect throughout food chains.

As atmospheric dynamics adjusted to the altered energy balance, unforeseen weather patterns have emerged. Rainfall distribution has dramatically shifted, causing both unexpected droughts and deluges in areas previously not affected by these extreme weather events. Diplomatic tensions are high as the geopolitical power dynamics fundamentally shifted in response to the newly defined ecological realities, resetting the political stage for the coming decades.

EFFECTS OF CLIMATE CHANGE

MONITORING CLIMATE CHANGE

Emissions

With increasing recognition of greenhouse gases (GHGs) as a significant driver of climate change, there is a pressing need to reduce these emissions. The United Nations' World Meteorological Organization (WMO) is taking the lead in ensuring standardized, real-time tracking of GHGs that can be used to influence policy making. WMO uses weather prediction and climate analysis to monitor greenhouse gases in an integrated framework. Another initiative is the Global Greenhouse Gas Watch, where WMO is collaborating with the global greenhouse gas monitoring community to ensure sustained and regular monitoring of GHGs. In this context, methane, a potent greenhouse gas, is important. Scientists posit that 60% of atmospheric methane results from human actions. To better monitor methane emissions, Harvard researchers, private space companies, activists, and philanthropists are launching the MethaneSAT project. Scheduled for 2024, the satellite will revolutionize methane monitoring by providing a comprehensive view of emissions across vast areas, surpassing existing aerial and ground-based methods. The core instrument of MethaneSAT is a spectrometer, a sophisticated device capable of precisely detecting methane concentrations. By monitoring methane emissions at a global scale with higher speed and efficiency, MethaneSAT can shed light on emissions' sources, pinpointing areas for targeted climate mitigation strategies.

Extreme Weather

The increasing frequency and severity of extreme weather events is causing significant challenges for insurers and communities worldwide. In states like Florida and California, insurance companies are withdrawing from offering homeowner insurance due to the growing risks associated with extreme weather events like hurricanes and wildfires. In Germany, insurers are demanding that house-building cease in flood-prone areas to mitigate potential damages. More accurate weather prediction could be helpful in such cases. Recent advancements in artificial intelligence have shown promise so far: Researchers from Nvidia, Google DeepMind, and Huawei have introduced machine-learning methods capable of predicting weather patterns as accurately as conventional methods and with much greater speed. However, given the unpredictability associated with future weather events, it remains to be seen if these AI-powered forecasting models trained on historical weather data can make proficient predictions. For extreme heat, Google is taking a proactive approach by partnering with the Global Heat Health Information Network to push notifications to users in affected locations. Addressing flooding risks, companies like C2S are leveraging technology to help insurers better understand and underwrite flood risk and monitor flood events in real time. Using machine learning, the company analyzes data from satellites, historical flood maps, and on-the-ground intelligence to provide insights into flood extent and impact.

In another initiative to decrease flooding risks, the National Digital Twin program is creating an interactive demonstrator tool to showcase how connected digital twins can enhance infrastructure resilience to flooding. Additionally, real-time flood sensors developed by the FloodSense project at NYU and the CUNY Advanced Science Research Center aim to provide hyperlocal street-level flood event information to stakeholders, including policymakers, government agencies, emergency response teams, and citizens. In the face of hurricanes, the National Oceanic and Atmospheric Administration is equipping forecasters with a new model called the Hurricane Analysis and Forecast System. The model offers earlier warnings of rapid intensification and improved predictions of impacts like rainfall and storm surge, empowering communities to better prepare for and respond to hurricanes.

Crops

In Africa, scientists are using artificial intelligence to predict the yields of vital crops by harnessing satellite remote sensing and machine learning. The tool can analyze vast agricultural landscapes, providing real-time predictions of crop yields and offering farmers and policymakers valuable insights into crop productivity.

MONITORING CLIMATE CHANGE

Community-based Efforts

With climate change becoming a global phenomenon, community movements have grown. In an attempt to make climate modeling easy, researchers from Northwestern University and Argonne National Laboratory have deployed Nvidia's Jetson-driven Waggle devices worldwide. Waggle is an open-source platform, empowering scientists and researchers globally to join climate studies using edge computing and sensors. The platform collects hyperlocal climate data, enabling communities to access crucial information for climate resilience. Parallely, a new collaborative, is blending indigenous knowledge with earth science to bolster climate resilience in vulnerable coastal communities by bringing indigenous knowledge-holders and university-trained scientists together. In India, a crowdsourced initiative brought together community scientists and professional researchers to develop a meteorology-based landslide prediction system called "Satark" for India's Western Ghats mountain range. With an impressive 76.5% accuracy, Satark predicts landslides along the southwestern coast a day in advance, safeguarding lives and livelihoods.

Digital Twins of Earth

To tackle climate change, researchers are experimenting with digital twins of Earth as part of a strategy to combat warming. The Nvidia Earth-2 initiative's digital twins could revolutionize weather predictions, climate projections, and the development of effective mitigation and adaptation strategies using data-driven analysis at the global scale. Powered by machine learning and accelerated computing, this groundbreaking project uses the largest supercomputing systems to make unprecedented advancements in weather information and climate emulation. The European Commission's flagship initiative, DestinE, is equally ambitious. Using technology to ensure high accuracy, local detail, access-to-information speed, and interactivity, this digital model of the Earth will monitor, simulate, and predict interactions between natural phenomena and human activities. It aligns with the European Commission's Green Deal and Digital Strat-

egy, furthering the goals of green and digital transitions and contributing to a sustainable future.

A digital twin of the earth is aiding with strategies against global warming.

LIVING IN A NEW REALITY

Floating Cities

The Institute for Economics and Peace predicts that by 2050, more than 1 billion people may have to deal with inadequate infrastructure due to sea-level rise. Floating cities will thus become a part of our new living reality. Projects like Oceanix City in Busan, South Korea, Baltic Sea islands developed by Blue21, and Maldives Floating City are great early examples of this. Oceanix, in fact, is built from biorock with the ability to self-sustain and self-repair. Another example is Waterbuurt, or the Water District, in Amsterdam, where 100 floating houses have been built by Dutch architect Marlies Rohmer on Lake Eimer.

Other Concepts for Cities

Smart Forest City, an ambitious project by Italian architect Stefano Boeri, was revealed in 2019 near Cancún. This visionary metropolis, deeply rooted in the region's Mayan heritage and culture's reverence for nature, is designed to house 7.5 million plants, creating a harmonious blend of urban living and green spaces. The company behind the project says the goal is to create a "perfect balance between the amount of green areas and building footprint." Equitism is the idea of an economic model empowering citizens with land ownership. Inspired by this idea, billionaire Marc Lore aims to establish a new American city called Telosa to "set a global standard for urban living, expand human potential, and become a blueprint for future generations." While the exact location is yet to be determined, the city's design by Bjarke Ingels Group places pedestrians and bikers at the forefront, supplemented by a few "slow-moving autonomous vehicles." Sustainability is at the city's core, with renewable energy, protected green spaces, and on-site water recycling. Targeting a population of 5 million by 2050, Telosa is poised to redefine the paradigm of urban development.

Underground Climate Change

Underground climate change is a silent hazard. In general, cities and urban areas release and hold heat more than rural areas. As cities heat up, the ground also traps more heat, affecting building foundations and, in some cases, leading the ground to expand, contract, and crack. Recently, scientists from Northwestern University have verified this phenomenon based on data from sensors in urban basements, subway tunnels, and underground parking garages. The study predicts that underground climate change in cities poses long-term challenges for urban structures, and researchers anticipate these issues will persist for years.

Indonesia's New Capital

Acknowledging climate change as an essential issue, Indonesia is building a new capital—Nusantara—that aims to transcend typical planned cities. The intent is to fulfill the Indonesian president's vision of "a new work ethic, new mind-set, new green economy." It will stand as a green metropolis powered by renewable energy, free from suffocating traffic jams, offering serene paths for strolling and biking amid lush greenery. Embodying adaptation to a warming planet, the high-tech city, also known as I.K.N., intends to attract digital nomads and millennials, who will embrace cryptocurrency to invest in chic apartments. Nusantara seeks to set a paradigm for a sustainable and forward-looking urban lifestyle.

Domed Cities

Cities with sealed bio-domes that control air temperature, air composition, and air quality are also being explored as a potential solution for cities affected by climate change. Saudi Arabia's Prince Mohammed bin Salman has a new vision for the country's capital in line with this idea: it will include a redesigned downtown with a 400-meter-high cube or "Mukaab." The cube will offer its residents immersive experiences, including changing landscapes and holographic technology. The project is called "New Murabba" and is scheduled to be ready by 2030. The city Riyadh will expand by 19 square kilometers as a part of the project. The country also has other futuristic projects underway, including Neom City, which plans to include robot maids, flying taxis, and a giant artificial moon and The Line, a huge project that will house 9 million people.

CLIMATE ECONOMY

CARBON CREDITS

Investment From Traditional Banks

Interest in carbon credits and green investing has increased as companies strive toward their net-zero emissions goals. Nine global banks have invested $45 million toward scaling a new platform called Carbonplace that will be able to handle more transactions of voluntary credits and make it easier for bank customers to participate. Carbonplace will connect credit buyers and sellers through the banks. The investors, UBS, National Australia Bank, BNP Paribas, and Itaú Unibanco among them, have invested $5 million each in the interest of accelerating corporate climate change through visible and secure means.

Verification Methodology

With increased interest in carbon credits, it's necessary to make sure the methods are sound to avoid greenwashing. One company, Isometric, is planning to do just that by launching a platform that can vet carbon removal companies and review new ones. It will include a list of fully verified carbon removal companies and the ability for scientists and researchers to view and comment on data provided by new companies, namely startups, that enter the industry. The Integrity Council for the Voluntary Carbon Market and the Voluntary Carbon Markets Integrity Initiative are joining together to craft a market integrity framework. This framework is built to instill confidence in investors using the Voluntary Carbon Market for their carbon credits and ensure top quality of all companies on the market. Governments are beginning to create their own frameworks as well, with the EU creating a Carbon Removal Certification Framework, which will influence the rules set in the Voluntary Carbon Market. Xilva, a Swiss company, is pursuing a similar verification but specifically for forest projects. The company provides an evidence-based assessment of a project's impact by considering multiple criteria such as economic viability, ecological integrity, and social equity in order to provide a holistic assessment on their platform.

Focus on Asset Management

Investors are frequently unsure if their credits are going to a verified company or one that is simply greenwashing. Sylvera, a UK-based startup, is on a mission to provide transparency and trust to carbon offset projects by using data and assigning ratings to the projects. Its goal is to ensure the projects with the best credibility receive investments in order to make a real climate impact. The company's recently closed Series B funding of $57 million will be used for US expansion.

Blockchain Integration

CarbonKerma is a platform that is embracing blockchain technology and combining it with a carbon capture marketplace in order to provide companies with trackable, quality, measurable carbon credits. The platform's listed credits are highly regulated and vetted through a stringent process. CarbonKerma offers a deeply needed value to the market: transparency. Each credit can be tracked, traded and, once removed from circulation, retired to never be used again. The visibility and auditability of this platform provides full transparency along with reputable carbon removal companies to ensure the quality of carbon removal.

Measuring Carbon Sequestration

The New Acre Project, which recently partnered with Albo Climate and ALUS, is an investment platform for corporations that is identifying carbon stocks and sequestration for trees using a remote sensing-based platform. This AI-powered product will be directed at four Canadian provinces: Alberta, Ontario, Quebec, and Saskatchewan. The participating sites are private lands managed by ranchers and farmers in the ALUS program. The credits will be "ecosystem credits" and will allow investment in any project that involves carbon removal, biodiversity, and other environmental benefits to the provinces.

BLUE ECONOMY

Blue Economy

The term "blue economy," originally championed by developing small-island countries including Fiji, Palau, and the Bahamas, was coined to describe the benefits of ocean industries. This includes establishing and supporting socially equitable ocean spaces and industries, ensuring they are environmentally sustainable, and that they can have an economic profit. The US highlighted a newly launched global initiative at the Our Ocean Conference, which would total more than $800 million to protect its ocean and support developing countries. The initiative focuses on securing and protecting marine areas and improving the resilience of coastal areas that could be impacted by climate change. European ports have received funding from the European Maritime and Fisheries Fund through the Atlantic Smart Ports Blue Acceleration Network to support the growth of new and sustainable business at more than 40 ports to grow the blue economy. The goal is to reduce the current carbon footprint of the port and increase the diversity of activities. Africa's blue economy is receiving attention after venture launcher Triggering Exponential Climate Action awarded $55,000 to seven startups to make an economic impact at a local level.

Blue Carbon Offsets

Blue Carbon Offsets are the management of marshes, mangroves, kelp, and seagrasses in ocean ecosystems for carbon offsetting. Indonesia and the World Economic Forum have signed an agreement aimed at improving the country's efforts by supporting a blue carbon roadmap. The blue carbon credit financing will help ocean conservation and restoration efforts. Researchers in China called the "Blue Carbon Catchers" are a collaboration between Tencent's Carbon Neutrality Lab and Xiamen University. The group is dedicated to understanding the ocean's capacity to act as a carbon sink and the future of its capacity.

Ocean Land Mapping

Marine Spatial Planning (MSP) is the ocean equivalent of land zoning planning and is helping to ensure the ocean is sustainably used. In a space that is used by so many, so frequently, and is home to so much wildlife, conflicts of interest are bound to arise when it comes to ocean activities. MSP serves as a clearly defined line for any disputes to ensure that all activities remain sustainable. It is frequently used to detect marine life or habitats and restrict building to the oceans' least impactful locations. MSP is frequently used by Manna Farms, a fish farming company, to ensure their practices remain sustainable.

Foundational Data US

The National Oceanic and Atmospheric Administration is providing free and open-source ocean and coastal data that provides a perfect foundation for the future blue economy. This data is used by a broad variety of organizations, from federal, state, and local governments, to academia and business and especially offshore aquaculture and wind farms. Open Ocean Robotics, a Canadian company, received $1.75 million to create an uncrewed, solar-powered surface vehicle that can capture information via sensors and cameras, and relay it instantly to researchers. The company's robot vehicles can travel on the surface of the ocean for months without stopping, producing carbon dioxide, making noise, or risking oil spills.

Data Platforms

Cognizant, a technology services and consulting company, has partnered with Tidal to make the company's ocean information platform available to the wider aquaculture market to allow companies to make more informed decisions. Tidal uses machine learning, artificial intelligence, underwater perception, and automation innovations to gather and analyze data sets. True Ocean, a German company, is also looking to provide companies with more maritime information and has already become a prominent maritime data platform. The platform offers solutions for data processing and management, empowering organizations to see the value of the data they hold by providing a suite of services with the goal of increasing efficiency and sustainable practices, and facilitating more educated decision-making.

BLUE ECONOMY

Fishing

GAIN (Green Aquaculture Intensification in Europe) is an EU project that has monitors and sensors located around fish farms and placed into fish to help track and understand the activities in the farms. Paired with machine learning and IBM analytics, this real-time information will help farmers make more informed decisions when it comes to protecting fish, as well as detecting and preventing problems such as fish escapes, environmental issues, and excess feed. There is also an increase in transparency in the life journey of fish, from the farm to the table. Atea, with the partnership of the Norwegian Seafood Association and IBM, is bringing this transparency by using the blockchain to track Norwegian salmon's journey including buyers and trips through customs. They believe that transparency is the key to sustainability and engaging society's awareness.

Desalination

Ocean Oasis, a Norwegian company, has found a way to use the oceans' natural wave power to produce fresh water. The company uses waves off Norway's coast to power their desalinator units and then fresh water is sent to shore through pipes along the ocean floor. This method of producing fresh water is sustainable and creates no emissions. EVOVE in the UK has developed technology to make the desalination process of water easier. Its Direct Lithium Extraction system removes the lithium from highly salinated water which increases the ease of the desalination process. The company is aiming to scale its technology to provide more efficient desalination processes on a global scale.

North Sea waves are aiding Nowergian company Ocean Oasis to desalinate water without causing emissions.

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MOBILITY · ROBOTICS · DRONES

Future Today Institute

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TOP HEADLINES

The mobility, robotics, and drones industries are building on their substantial gains of the past year to increase capabilities and capacity.

01 Demand for Customization Outweighs Supply Chain Delays

Even as supply chains bounce back from extreme conditions, customers have indicated they are willing to wait for what they want, impacting traditional business models.

02 Vehicles Are No Longer a Private Refuge

While vehicles have traditionally functioned as a utility to get us from point A to point B, they are now following and integrating into our digital lives, eliminating one of the last spaces that was not immersed in tech.

03 Battery Capacity Drives Capability

The expanded capacity and shifting form factors of emerging battery technology are enabling units to go further, faster and take on a higher compute load to enhance their capabilities and communication.

04 General Purpose, Yet Impressive, Results

General-purpose robots are moving closer to reality. As bots become more capable, they will be more versatile, able to execute on a variety of different tasks.

05 Cobots Merely Supplement Staff, for Now

Assistive robots promise to help humans be more efficient at their jobs and supplement a shrinking labor force, but as bots improve, inevitably, they will eliminate the need for humans to conduct certain tasks.

STATE OF PLAY

Overcoming challenges to electrify and bring about the age of smarter, autonomous systems.

While the diverse industries of mobility, robotics, and drones have prominent differences impacting each domain, they also have common drivers. Electrification remains a major driver of change for all of them thanks to the support of consumer and ESG (environmental, social, corporate governance) demands, coupled with global, legislative shifts bringing an electric future to the forefront.

Fully autonomous systems are still on the horizon, especially for automobiles, but systems are becoming smarter and more alive. A wealth of data is proving to be foundational for molding these systems, and virtual and simulated testing environments are increasingly being used to teach them before they are placed in real-world environments.

Although these systems are getting smarter, they are still fraught with challenges. There is a vast dichotomy between those that have been successfully testing and expanding in select US markets, while others have been forced to halt real-world operations after too many public failures.

Similarly, in the world of robotics, a general purpose, fully autonomous humanoid robot has long been a dream of many and presented as a holy grail of innovation. However, while there are early signals of such robots, they are unlikely to fully supersede the human workforce any time soon, with most job replacement coming from functional robots with a limited task set. Contrastingly, drones have already been successfully impacted by autonomous systems and are seeing annual capability enhancements across commercial and consumer sectors.

The bifurcation of these industries will likely continue as the world pushes to bring about electrified replacements for billions of vehicles and impart autonomy to make vehicles, robots, and drones smart enough to drive real efficiency gains across the marketplace.

KEY EVENTS

MAY 25, 2023

Ford Teams Up with Tesla
The automakers align to use the NACS plug, promoting industry standardization for charging.

AUGUST 14, 2023

Self-driving Cars Block Ambulance
Two autonomous cars prevent an ambulance from getting to a crash site, delaying an injured pedestrian's transport.

OCTOBER 30, 2023

Cruise Suspends Robotaxis
The GM business puts a stop to operations in Arizona and Texas, after having to halt operations in San Francisco.

AUGUST 04, 2023

Ukrainian Drone Attack
A Ukrainian drone with 450kg TNT hits a Russian Navy base in the Black Sea, damaging a docked warship.

SEPTEMBER 19, 2023

AI Masters Complex Tasks in Hours
Toyota Research Institute engineers use generative AI to teach robots new skills quickly and with dexterity.

LIKELY NEAR TERM DEVELOPMENTS

MORE CERTAINTY IN COMPLEX SYSTEMS

In the immediate future, a wave of transformative development is poised to reshape our world across various domains. From the continued integration of connectivity in automobiles—fueling advanced driver assistance systems and enriched in-car experiences—to the pressing challenges facing our electrical grids as we pivot toward an all-electric future and the changing regulatory landscapes impacting drones and autonomous systems, these developments underscore the dynamic nature of technological progress. They collectively signify an era of both challenge and opportunity, where adaptability and forward-thinking will be key to navigating the disruptive forces of technology.

Continued Connectedness

Automobiles are only becoming more connected. This will impact advanced driver assistance systems as well as infotainment within the cabin. Automobiles will be less isolating as drivers and passengers seamlessly expand how they connect to their lives outside the car.

Supply Chain Disruptions Persist

Even as the supply of vehicles and chips for robotics stabilizes, manufacturers and sellers should still brace for continued supply chain disruptions. Additionally, chip nationalism and other geopolitical factors will also threaten supplies of goods.

Viability of Drone Traffic Management

The escalating use of drones and eVTOLs has necessitated advanced traffic management solutions. As various regions have put measures in place, the viability of ubiquitous drone use will be determined in the short term.

Challenges to the Grid

As we idealistically transition to an all-electric future, many have speculated our electrical grids will not be able to handle this adjustment. Others are more optimistic. In time, we will have more certainty.

New Modalities for Robotics

Researchers have developed many innovative modalities for robotics and drones, seeking inspiration from various sources. This innovation will continue, with unexpected inspiration from nature or animals, and some systems will incorporate several different modalities in their designs.

Clarity on Robotaxis

Robotaxis have been the source of much controversy, as different companies have tested their systems with varying success. The near future will shed light on long-term feasibility, especially as regulations shift to account for recent events and developments.

11 MACRO SOURCES OF DISRUPTION
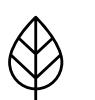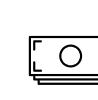
| Technology | Media & Telecom | Demographics | Environment | Government | Public Health | Education | Geopolitics | Infrastructure | Economy | Wealth Distribution |

WHY BUILT MOBILITY, ROBOTICS & DRONES TRENDS MATTER TO YOUR ORGANIZATION

A Deluge of Data

Increased connectivity and semiautonomous systems have led to a rise in data collection. This, combined with information gathered from fleets, vehicles, or bots, can provide valuable insights for improved decision-making and product development.

The "Threat" of Decarbonization

Transportation is one of the leading contributors to carbon emissions. The regulations are already affecting the industry, and this trend is expected to continue. Although many manufacturers have adopted electric strategies, they still need to take steps to proactively offset more of their emissions.

New Applications for Robotics-as-a-Service

As businesses explore ways to enhance their workforce or even automate their operations, it may not always be beneficial for them to personally own their own fleet of robots. A comprehensive understanding of robots' full capabilities can help businesses determine whether it is better to own the robots themselves or outsource for the service.

Optimizing Your Workforce

As collaborative robots continue to advance and become more sophisticated, businesses have a chance to improve the efficiency of their workforce and complete tasks quicker. By incorporating collaborative robots, companies can also safeguard their employees from harsh working conditions. Keeping up with these trends is vital for optimizing workforces.

Leveraging Last-Mile Delivery

The regulatory and technological landscapes for last-mile delivery are evolving. Companies that can both master the technology and stay ahead of regulatory changes will be well-poised to serve their customers effectively, providing goods and services quickly and efficiently.

Dramatic Changes to Insurance

As systems become semiautonomous and fully autonomous, insurance strategies will need to adjust. This will impact automobiles, robotic systems on warehouse floors, and even employees whose roles change in light of collaborative and assistive robots.

WHEN WILL MOBILITY, ROBOTICS & DRONES DISRUPT YOUR ORGANIZATION?

Forecasted Time of Impact

0-4 YEARS	5-9 YEARS	10-14 YEARS	15+ YEARS
Transportation	Grid management	Space exploration	All trends will be relevant
Infrastructure development	Energy storage		
Supply chain management	Manufacturing		
Energy generation	Construction		
Warehouse management	Health care		
Delivery	Eldercare		
Last-mile delivery			
Prosthetics			

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OPPORTUNITIES & THREATS

Threats

OEMs, and other automotive service and parts players, are facing uphill pressures if they fail to adapt to the growing electric market. The longer-term threat will persist as more customers seek green options and governments phase out fossil fuel-powered vehicles.

As vehicles gain more ability to observe and control the passengers within them, the industry is creating entirely new venues for privacy and data security concerns. With increased levels of data collection, automobiles are becoming a more attractive cyber-infiltration point, posing risks for OEMs, third parties, and customers.

The rapid adoption of EVs could potentially lead to an increase in brownouts, electrical surges, or fires resulting from overloading home or even commercial electrical systems. As EV adoption scales, real estate is at a greater risk of damage and increasing insurance premiums, until the infrastructure modernizes and stabilizes.

As bots become more dynamic and function across multiple modalities, organizations that fail to adopt general-purpose robotics could be at risk of falling behind competitors that masterfully incorporate these systems into workflows.

While the applications for robots and drones become seemingly endless, organizations that are slow to conceive and execute new ways of using these systems risk underserving their customers and their employees.

Opportunities

To get more electric vehicles on the road, manufacturers can look for new and novel partnerships to drive adoption. Partnerships such as ones that assist gig workers in leasing EVs can serve as the template for new programs.

Technology companies and startups have a significant opportunity to create seamless experiences across all mobility modalities, providing consumers with multiple options for arriving at their desired destinations with minimal friction.

As bidirectional charging becomes more pervasive, the traditional role of cars is transformed. Vehicles can now be the powerplant that runs a home or business in an emergency and could potentially run full time as capabilities and capacities increase.

When cobots create efficiencies and robotics begin to automate repetitive and even dangerous tasks, organizations can upskill their workforce to engage in more creative and meaningful undertakings, bringing new value to the organization.

Training robots and drones in virtual and simulated environments allows these systems to learn complex tasks virtually before transitioning to the real world. Championing this process will place organizations in enviable positions.

INVESTMENTS AND ACTIONS TO CONSIDER

1

As autonomous systems become more prevalent, data will continue to be widely available. Businesses can utilize advanced machine learning and AI to unlock new insights that can feed into new products and services. This leads to opportunities to surprise and delight customers along their journeys.

2

For transportation industry leaders, focusing on sustainability is now a basic requirement. However, leaders should not become complacent in their efforts and must continue to push for new technologies that can provide competitive advantages, such as better and smaller batteries.

3

Consider calculated investments in collaborative and assistive robots, which can supplement strained workforces and create efficiencies. However, there is not a blanket call for organizations to pursue such solutions. They will have to balance the threat of not acting with the capital expenditures required for adoption.

4

Pilot and passenger observation technologies might seem invasive to drivers and passengers, but investment in this tech can reduce accidents and save lives. In a future where autonomous driving becomes viable, these systems can be transformed to assess and anticipate the wants and needs of passengers, providing new ways to reach them.

5

Electrification is radically changing the transportation industry, and there will increasingly be new ways to engage with consumers who experience this new paradigm. Consider new products and services as passengers wait for their charging vehicles, providing opportunities for companies outside the traditional transportation industry.

6

Investing in robot compiling and training technologies has the potential to radically accelerate robots' abilities to learn and to adapt to their environments in real time. While hardware is very important to robotics, software is equally, if not more, important, potentially resulting in efficiencies that compound in time.

CENTRAL THEMES

Electrification Upends the Industry

As electrification becomes more pervasive in the world of mobility, the entire industry is being drastically redefined. While electric vehicles' range increases, spurring more adoption of EVs, the roadside experience is radically changing to include opportunities to engage drivers and passengers in novel ways. The advent of electrification is having impacts on the traditional business models associated with dealerships, forcing significant restructuring of how business is done. Repair servicing is at significant risk, as electric vehicles require less maintenance and different skill sets for making repairs. This shift is affecting supply chains and changing the types of materials needed, forcing manufacturers to make substantial investments in areas such as lithium processing. Electrification is also having an impact on safety standards, as EVs are less likely to be heard by bystanders. Amid electrification's scaling, stakeholders must fully consider its implications on the future.

Better Batteries Boost Improvements

Electrification of the broader industry will continue to face a "chicken or the egg" dilemma—battery capabilities must grow to drive electrification demand, and electrification demand must grow to drive battery technology. However, battery development continues to press forward, with capacity improvements, efficiency gains, and shrinking or altering of form factors to make them more relevant and useful. Improvements are helping increase the range of vehicles or the operational time of drones and robots, reducing the "range anxiety" of consumers and commercial buyers alike. These updates also enable these vehicles and units to focus more power on their compute abilities either in a trade-off for range or in addition to that extended range. This is leading to a new class of devices and vehicles that are more powerful and capable than ever before over longer time spans and distances.

Expanded Capacity and Capability

In both automobiles and mobility at large, robotics and autonomous systems are growing in their capacity to do tasks and support payloads, while their overall capabilities are increasing, too. These achievements are due to advances in both hardware and software. A constellation of vision, audio, and touch sensor systems, including lidar, radar, 2D and 3D cameras, accelerometers, gyroscopes, bump sensors, force sensors, and temperature sensors are enabling these devices to better sense the environments around them. Advanced methods for training and modeling, including using virtual elements to simulate training scenarios, are increasing these systems' capabilities and helping them achieve new thresholds of what is possible on even shorter timelines. As these systems become more adept and dexterous, they also benefit from increased strength and increased payload capacity. And as they become more dynamic, they will be better equipped to tackle new challenges.

CENTRAL THEMES

Maximizing Connectivity and Communication

The increased capabilities of vehicles, robots, and drones mean they can use their additional sensors and software to know more about their environments. This also requires these form factors to collect substantially more data than ever before and, in most instances, communicate back to their OEM, a third party, the end user or owner, and even each other. This is forcing product and vehicle designers to more closely consider the connectivity needs of these devices and the potential partnerships required to enable these higher levels of communication. As levels of autonomy increase over time, the compute load will as well, in addition to the vast amounts of data that will need to be collected in real time, and then streamed back and forth to the cloud's future iteration.

Mimicking Your Surroundings

When it comes to designing complex systems, nature is a meaningful muse for development and execution. To achieve fluid movement for robots, engineers often find inspiration from the movements of creatures and plants like jellyfish, caterpillars, and even vines—these allow the bots to be dynamic and even reactive based on external stimuli. Organic material also lends itself to the material design of robots, where tissues of specific organisms become instrumental in optimizing the functionality of a bot. Organisms, both living and dead, are increasingly finding themselves as key components of a robotic system, functioning as hands or grippers to lift and move objects. Organisms even factor into the training of robotics, as engineers have used ants as inspiration for enhancing the navigation capabilities of robots in challenging terrains. As robotics design remains challenging, nature will continue to provide valuable design solutions.

Tempered Autonomy

The development of autonomous systems is a major driving force for scientific advancement across the domains of mobility, robotics, and drones. Although the promise of fully autonomous vehicles has not yet been fully realized, autonomous driver assistance systems have significantly impacted the automotive industry and provide a strong signal for increased autonomy in the future. In the field of robotics and drones, varying degrees of autonomy are required for efficient and effective operation. The methods for programming these systems are becoming more sophisticated but are still in the early stages of refinement. As the technology advances, the level of autonomy in these systems is expected to continue increasing, leading to more efficient and advanced robotics and drones. The future of these domains heavily relies on the development of autonomous systems, and the progress made in recent years reflects a positive step toward achieving fully automated systems in the future.

ONES TO WATCH

Sertac Karaman, associate professor of aeronautics and astronautics at MIT, for his contributions in driverless cars, unmanned aerial vehicles, distributed aerial surveillance systems, air traffic control, and certification and verification of control systems software.

Aaron Becker, associate professor of electrical and computer engineering at the University of Houston, for his contributions to swarm robotics, distributed robotics, medical robotics, and motion planning.

Jonathan How, professor of aeronautics and astronautics at MIT, for his role in developing algorithms that keep drones from colliding in midair.

Bilin Aksun Güvenç, research professor in the Department of Mechanical and Aerospace Engineering at The Ohio State University, for her role in the development of Vehicle-in-Virtual-Environment testing, which allows testing of driverless cars in a safe virtual environment.

Steven Hartley Collins, associate professor of mechanical engineering at Stanford University, for his contributions to versatile prostheses and exoskeleton design.

Martin Nisser, a Ph.D. candidate in the HCI Engineering Group at MIT's Computer Science and Artificial Intelligence Laboratory (CSAIL), for his efforts to democratize robotics and hardware by creating self-configurable and self-assemblable systems that address a diverse functionality of needs.

Chris Anthony and **Steve Fambro,** co-CEOs of startup Aptera Motors, for working to leverage a lightweight chassis, low-drag aerodynamics, solar cells, and materials science to provide high efficiency solar electric transportation.

Wei Wang, researcher at the US Energy Department's Pacific Northwest National Laboratory, for his contributions to using sugar to design better flow batteries.

Gill Pratt, CEO of Toyota Research Institute, for his role in using generative AI technology to quickly teach robots new, dexterous skills.

JB Straubel and **Andrew Stevenson,** co-founders of Redwood Materials, for pioneering circular supply chains and recycling pathways for end-of-life EV batteries.

Dr. Pisak Chermprayong and **Dr. Ketao Zhang,** who as researchers at the Imperial College London produced innovative work on 3D printing with drone swarms.

Daniel Preston, assistant professor of mechanical engineering at Rice University, for pioneering necrobotics.

Jensen Huang, founder of Nvidia, for his vision in enabling key components for robotics, autonomous systems, and AI.

Dr. Robert Playter, CEO of Boston Dynamics, for pushing the robotics industry forward while pledging to never weaponize technology, and other efforts to instill public trust.

Dr. Marc Raibert, founder of Boston Dynamics, for his dedication to the study of dynamic moving systems, including robots with legs, simulated mechanisms, and animated figures.

Henry Liu, professor of civil engineering at the University of Michigan, for his contributions to the first realistic simulated driving environment based on a "crash-prone" Michigan intersection.

Manoj Raghavan, CEO of Tata Elxsi, for his vision in leading a company whose advanced sensors and AI algorithms aim to keep individuals safe from the hazards of driving.

Michael Smith, postdoctoral researcher in soft robotics at EPFL, for his work in developing flexible, stretchable pumps for soft robotic systems.

Jocelyne Bloch, neuroscientist and neurosurgeon at Lausanne University, for her work in functional neurosurgery.

Giuk Lee, associate professor at Chung-Ang University, for his work on assistive exoskeletons and wearable robots.

Hyung Ju Suh, Ph.D. candidate in electrical engineering and computer science at MIT's CSAIL, for his work in enabling robots with human-like dexterity and intelligence in manipulation.

Russ Tedrake, Toyota Professor of Electrical Engineering and Computer Science, Aeronautics and Astronautics, and Mechanical Engineering at MIT, for his work in combining systems theory and robot manipulation.

Zachary Manchester, assistant professor of robotics at Carnegie Mellon University, for his efforts to enable robotic systems to match or exceed the level of agility, efficiency, and robustness demonstrated by humans and animals.

Josephine Galipon, associate professor at the Graduate School of Science and Engineering at Yamagata University, for exploring the potential benefits of collaborations between robots and living creatures.

IMPORTANT TERMS

MOBILITY

ADAS (advanced driver assistance systems)
Technologies that assist drivers by performing certain functions in a vehicle, such as blind-spot monitoring, lane departure warning, pedestrian detection, emergency braking, and traffic sign recognition.

AMD (assistive mobility device)
A mobility aid such as a wheelchair, scooter, walker, or orthotic.

Bidirectional charging
A system that enables an electric vehicle to transfer electricity back to the grid, as well as to charge using electricity from the grid.

EV charging port
The connector that supplies power to an electric vehicle when it is plugged in. Of the different connector types the most common in the US is the North American Charging Station, or NACS. Tesla uses it, and more manufacturers are adopting this connector.

ICE (internal combustion engine)
An engine powered by fuel combustion, most commonly gasoline or diesel fuel.

V2G (vehicle-to-grid)
Allows bidirectional charging so electric vehicles can receive electricity from a charging station, or share their stored electricity with the grid.

V2I (vehicle-to-infrastructure communication)
Enables vehicles to communicate with traffic lights, RFID readers, cameras, lane markers, and other parts of the physical world.

V2V (vehicle-to-vehicle communication)
Allows vehicles to exchange information with other vehicles, sharing data such as speed and location.

Levels of Automation
The Society of Automotive Engineers (SAE) clearly defines six levels of driving automation:

- **Level 0**
  No Automation
  A human driver manually performs all tasks.

- **Level 1**
  Driver Assistance
  A driver controls the vehicle, but the vehicle design may include some driving assistance features.

- **Level 2**
  Partial Automation
  The vehicle has combined automated functions, like steering and acceleration. However, the driver must always remain engaged and monitor the environment constantly.

- **Level 3**
  Conditional Automation
  A driver is essential. Driver does not need to monitor the environment, but must be ready to assume control at any time.

- **Level 4**
  High Automation
  The vehicle is capable of performing all driving functions under specified conditions. The driver has the option to take control.

- **Level 5**
  Full Automation
  The vehicle is capable of performing all driving functions under all conditions. The driver may have the option to take control.

LEVELS OF EV CHARGING

There are three levels of charging. The higher the level, the less time it takes to reach a full battery.

- **Level 1**
  These charging stations use a standard 120v outlet. The time to charge a vehicle's battery can take 60 hours or more.

- **Level 2**
  These are the most commonly available charging stations and are used most often for home charging. The time to reach a full battery is around 11 hours.

- **Level 3**
  There are two types of rapid charging stations: DC Fast Charging and Supercharging. Level 3 stations can fully charge a battery in under 30 minutes and most closely resemble the customer experience of gasoline-powered cars. Tesla's standard is Supercharging, and the company has the largest network of Level 3 charging stations in North America.

IMPORTANT TERMS

ROBOTICS

Cobot
A collaborative robot built for interaction with human workers, assisting with certain tasks, often those that are repetitive or harmful to humans.

Exoskeleton
A rigid, mechanical robotic structure that encases the human limb, or envelops the body, and assists the wearer in motion-based activities, such as walking or lifting.

Microrobotics
A field of robotics that develops miniature robots, typically smaller than 1 mm (or .001 meters) in size.

Nanobot
A field of robotics that develops robots at the scale of a nanometer (or 10-9 meters).

Necrobotics
A field of robotics that utilizes biological material, such as insect cadavers, as robotic components.

Quadrupedal robot
A four-legged robot.

Robotics
The use of a physical, mechanical device capable of performing tasks at various levels of complexity, either on command or via preprogrammed instructions.

DRONES

AGV (automated guided vehicle)
A robot that follows specific lines, lanes, or other markings, often used in industrial settings.

AUV
Autonomous (or uncrewed) underwater vehicle.

BVLOS (beyond visual line of sight)
Operating an UAV outside of the visual line of sight of the operator.

Drone
An unmanned vehicle that can operate in the air, on land, or in the sea:

- **Fixed-wing drone**
  A drone with one rigid wing, resembling an airplane. It is typically capable of remaining in the air longer and flying longer distances than other drone types.

- **Fixed-wing hybrid VTOL**
  A drone with a rigid wing, and rotors that are attached to either side, enabling vertical takeoffs and landings.

- **Single-rotor drone**
  A drone with a single rotor on top, much like a helicopter.

- **Multi-rotor drone**
  A drone with multiple rotors. The most common multi-rotor drone is a quadcopter, which has four rotors.

- **Drone swarm**
  Fleets of networked drones capable of coordinated operations and communication.

- **eVTOL (electric vertical take-off and landing)**
  An electric-powered drone that has the ability to take off and land vertically, as well as hover.

- **Federal Aviation Administration (FAA)**
  Drone operators are required to comply with FAA rules. There are a multitude of airspace restrictions as well as FAA-Recognized Identification Areas (FRIAs). In a FRIA, a drone operator may fly their device without Remote ID.

- **UAV**
  Unmanned aerial vehicle.

MOBILITY TRENDS

ELECTRIFICATION TRANSFORMS MOBILITY ECOSYSTEMS

Decarbonizing Mobility

In the US, the transportation sector generates the largest amount of greenhouse gas emissions—primarily from burning fossil fuel for cars, trucks, ships, trains, and planes. In efforts to mitigate climate change, this industry is a prime candidate for impact. Some states offer proactive examples. California allocated more than $50 billion in funds to address climate change and move away from the use of fossil fuels. In the area of transportation, the state is implementing regulations to reduce toxic freight pollution and accelerate the deployment of zero-emission trucks; officials are also allocating emergency funding to ensure the safety of public transit riders and workers, in hopes of persuading more people to choose that form of transportation. California also enacted a Low Carbon Fuels Standard to ensure that it aligns with climate and environmental justice priorities. In Europe, the transportation sector is also a major contributor of greenhouse gasses, and officials are aiming for a 90% reduction to meet the EU's target of carbon neutrality by 2050. This transition poses significant challenges for European cities, which significantly contribute to these emissions; to support them in this effort, the EU is offering help creating Sustainable Urban Mobility Plans. However, various obstacles, including governance issues, need to be addressed. Additionally, the Council of the European Union has recently passed a new regulation aimed at facilitating EV travel across the continent while mitigating the impact of greenhouse gas emissions. The regulation mandates the installation of fast charging stations that offer a minimum of 150 kW of power at a maximum distance of 60 km (37 miles) from each other along the Trans-European Transport Network (TEN-T) highway system by the year 2025. As more electric mobility technology is adopted, cost structures and operations will continue to change. The mobility industry, including vehicle manufacturers, is already feeling the impact and rethinking business models.

Automaker Restructuring

Major car companies and transportation platforms are making significant investments in an electric future, with plans and announcements from the late 2010s now becoming reality. Western automakers are even investing in lithium mining companies to ensure a stable supply of this key component of EV batteries, committing billions of dollars to secure the resource. General Motors has invested $650 million in Lithium Americas to develop the Thacker Pass Mine in Nevada and has entered into supply agreements with lithium companies like Livent. Ford has arranged lithium supply deals with Chilean supplier SQM, Charlotte-based Albemarle, Nemaska Lithium in Quebec, and the Argentina mining company Rio Tinto.

Ford and Uber are collaborating through the Ford Drive program to provide flexible leases of EVs to Uber drivers. The goal is to support Uber's efforts to convert more drivers to EVs and reduce emissions, while Ford will benefit from expanding the presence of its Mustang Mach-E EVs. The initial pilot program offers one- to four-month leases in San Diego, Los Angeles, and San Francisco.

School districts are replacing traditional buses with electric models to reduce emissions and save on fuel costs, with potential orders up to $1 billion over the next five years. Blue Bird has opened a new Electric Vehicle Build-Up Center in Georgia to meet the increased demand for electric school buses, and aims to increase production from 100 to 5,000 electric buses annually. Blue Bird will assemble its "Vision" and "All American" buses, each with a 155 kWh battery providing 120 miles of range.

Mass Market Goes Custom

During the COVID-19 pandemic, the shortage of semiconductor chips caused significant supply chain constraints. The lack of chips, used in automotive parts such as operating systems, cameras, sensors, and entertainment systems, led to a decline in production, resulting in a shortage of vehicles. Dealers had little to no stock on their lots and were forced to operate as showrooms, where some customers placed orders for a custom vehicle with a longer lead time. While supplies are slowly and tortuously improving, CEOs of major car brands anticipate that inventory

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levels will never go back to where they were pre-pandemic. But this window has revealed that customers will wait and pay for their dream car, with the ability to pick their desired color, features, and accessories. Consequently, build-to-order purchases will likely continue to increase and render big vehicle inventories less necessary. Ford is extending this schematic to its Mustang Mach-E, offering a $1,000 discount in some instances for customers who pre order. This trend is likely to continue as more production lines shift to increased EV manufacturing. Such a shift does have tremendous implications for the industry, changing the nature of dealerships and impacting current commission and profit-sharing structures. Both the industry and consumers will have to adjust to such restructuring, and adequately prepare for impending shockwaves.

Incentive-Driven Investments

Many vehicle manufacturers and battery makers are investing heavily in the development of electric vehicles and their future success. A recent analysis by Atlas Public Policy reveals that a total of $860 billion will be invested globally by 2030 toward the transition to EVs. In the US, investments are expected to total $210 billion—almost a quarter of the entire investment. Amid this spending increase, some of the benefits are trickling down to consumers. Increased plant capacity, production scaling efforts, and improved battery material costs are enabling Ford to reduce the prices of its F-150 Lightning electric truck models by up to $10,000 to incentivize sales. The base F-150 Lightning Pro will be priced at $49,995. Elsewhere, Geely announced the Galaxy E8 sedan (about the size of a Honda Accord) will be on sale in the Chinese market for under $25,000. Automakers are also taking advantage of tax incentives associated with EV production. The state of Georgia has offered Rivian $1.5 billion in tax incentives for the company to build a $5 billion factory east of Atlanta. There, Rivian plans to produce 400,000 electric vehicles annually and provide 7,500 new jobs after officially getting the green light to move forward with production. While tax credits have been effective at enticing consumers to purchase EVs, the Inflation Reduction Act has unexpectedly complicated the practice. In August 2023, the law restricted the $7,500 tax credit to only EVs assembled in North America. As a result, automakers that can no longer incentivize new car buyers this way are encouraging consumers to lease EVs.

Global Battery Belts

Major players in the automotive and battery chemistry industries are investing in US battery production. States that attract electric vehicle manufacturing and battery plants highlight the job opportunities these investments create, not only within the plants themselves but also in the surrounding supplier and logistics sectors. The growth in EV manufacturing is especially prominent in the Battery Belt: The area, which runs from Detroit to Georgia, offers lower electricity costs and strong manufacturing employment growth, driving industry expansion. As an example, Hyundai Motor Group and LG Energy Solution announced a joint investment of $4.3 billion in a new electric battery plant in southeast Georgia. By late 2025, the plant expects to be producing batteries for electric vehicles and aims to accelerate the production of electrified Hyundai and Kia vehicles in North America. But despite this push by US companies to produce more batteries, most production is still dominated by China. Last year, China refined approximately 95% of the world's manganese, around 70% of cobalt and graphite, two-thirds of lithium, and over 60% of nickel, all of which are vital components in the production of lithium-ion batteries. In time, that could change, especially with the 2023 discovery of lithium in a US volcano along the Nevada-Oregon border, which could result in a stable and sustainable source of the metal for the US for decades to come.

Battery Recycling

The debate surrounding the sustainability of EVs versus internal combustion engine vehicles (ICEs) revolves around the environmental impact caused by the mining of lithium and cobalt, which are crucial materials for batteries. However, by using recycled battery components, the need for new mineral mining can be reduced, leading to a more environmentally

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friendly EV market. Currently over 80 companies worldwide are engaged in the recycling of electric vehicles, with over 50 startups receiving at least $2.7 billion in funding from corporate investors such as automakers, battery manufacturers, and mining companies. Industry insiders predict that by 2040, up to 40% of the battery materials used in new electric vehicles could come from recycled sources. A prominent player in this space, Redwood Materials, has partnered with Ford and Volvo to establish responsible disposal and recycling pathways for end-of-life EV batteries. They are also going beyond EVs and collaborating with Rad Power Bikes to conduct the same process for retired e-bike batteries. Ascend Elements has secured $542 million in Series D funding along with $480 million in earlier Department of Energy grants for recycling lithium batteries into black mass to be reused in other materials. Additionally, Nth Cycle has secured a focused Series B funding round of $50 million, and Green Li-ion has received $20.5 million in funding to support its recycling initiatives.

Better Batteries

Electric vehicle manufacturers and their partners are working hard to improve batteries by exploring new battery types, designs, and materials. The development of solid-state batteries and other innovative battery solutions will make batteries smaller, safer, and capable of providing longer ranges, much like the Harvard John A. Paulson School of Engineering and Applied Sciences (SEAS) research that developed a new way to make solid-state batteries with a lithium metal anode. Beyond the obvious safety and range benefits, enhanced batteries will provide greater versatility in terms of battery shape, which will allow for more options in different mobility platforms and provide more cabin space in vehicles. QuantumScape is striving to make solid-state batteries available to the public as early as this year. This technology will allow EVs to travel up to 400 miles on one charge and recharge in only 15 minutes. Toyota plans to be using solid state batteries by 2028, reducing the size, cost, and weight of its EV batteries by 50%. General Motors is investing $60 million

in Mitra Chem to use iron-based cathodes to make battery technology more accessible and cost-effective. Researchers at Pacific Northwest National Laboratory have developed a breakthrough in flow battery technology by using a solution based on sugar to lead in the development of low-cost, long-duration energy storage systems, which could impact the source of energy for charging EVs. Startup Ample is taking a different approach, focusing on battery swapping as a means to keep EVs on the road.

Solar Vehicles

Solar-powered EVs require less frequent charging and can increase efficiency. A recent study found that solar-powered cars can travel between 11 and 29 kilometers per day using solar energy, reducing the need for frequent charging. These solar cars have the potential to make electric transportation cleaner and more affordable by minimizing pollution from electricity production. Dutch startup Lightyear saw the advantage of solar, but despite its efforts, was declared insolvent in 2023 shortly after releasing its

$250,000 Lightyear 0 solar car. After raising more capital, the company will try again with a more affordable Lightyear 2, which has a starting price of $40,000. First revealed as a concept, Kia's EV9 SUV features solar panels to supplement its 100-kilowatt-hour battery; the company started taking reservations for the EV9 in late 2023. In contrast to a large SUV, California-based Aptera Motors focuses on producing ultra-efficient EVs through aerodynamics and weight savings. Its three-wheeled EV, the Aptera, boasts a highly aerodynamic design with a drag coefficient of 0.13, offering up to 400 miles on a single charge, which can be supplemented through included solar panels. While solar vehicles will not eliminate the need for charging any time soon, their integration will help the industry move toward more sustainable transportation.

Shifts in the Servicing Model

While the mobile service model is not new, it's increasingly impacting the mobility and automobile industry. Now, mechanics can travel to meet customers in their physical locations, and over-the-air updates can, in some

ELECTRIFICATION TRANSFORMS MOBILITY ECOSYSTEMS

instances, resolve digital-based issues. As the model takes hold, this presents a significant threat to traditional dealership/servicing models, and companies are racing to adapt. Rivian plans to repurpose large commercial Amazon vans to function as mobile service vehicles for its consumer and commercial vehicle fleet. These electric Rivian Service Vans will offer maintenance, repair, and vehicle-to-vehicle charging. Ford is recognizing the need to enhance the vehicle service experience and is moving to expand its remote service offerings. The company will be providing complimentary pickups and deliveries of its vehicles and mobile repair options to more of its customers. Startups are also taking advantage of this shift. On-demand car care startup Spiffy has acquired $30 million in funding to aid car dealerships in expanding its mobile service offerings. Through sales of its software and van upfits, Spiffy plans to help dealerships and repair shops provide mobile brake maintenance and oil changes. Repair servicing is really beginning to go the extra mile to win customers and foster and enhance relationships.

Electrification Expands to Other Vehicles

The rise in electrification of vehicles is extending beyond consumer cars. Delivery carriers like Amazon and the US Postal Service are investing in the technology: Amazon aims to deploy 100,000 electric delivery vehicles by 2030, and the USPS says it will buy over 66,000 electric vehicles by the end of 2028. When it comes to aviation, ZeroAvia has successfully flown the world's largest hydrogen-electric aircraft as part of the HyFlyer II project, a government-funded initiative aimed at making small passenger planes more environmentally friendly. Magpie Aviation, a California company, has proposed using electric aircraft as towing planes to connect with passenger or cargo planes that have sufficient battery power for takeoff, landing, and flight to alternative airports. Electric boating is impacting both small and large-scale initiatives. BMW and Tyde have launched the ICON electric boat, a 43-foot eco-friendly vessel powered by hydrofoils, six BMW i3 batteries, and two electric motors. It has a range of more than 50 nautical miles and a max speed of 30 knots. On

the other end of the spectrum, China has unveiled its first battery-electric container ship, the 700 TEU, which has a capacity of carrying 700 20-foot containers. Even micro mobility is becoming electrified, as the e-bike company Cowboy introduces a more affordable Core line of its e-bikes and startup AtmosGear has unveiled electric inline skates featuring a 20-mile range on a full charge.

Amazon Prime electric delivery vans built by Rivian on the street in Seattle.

Image credit: 400tmax/istock.com

VEHICLE CHARGING SCALES

Charging Gets A Roadmap

The electric vehicle revolution is well underway, but a key bottleneck remains a concern: charging infrastructure. Rural and suburban consumers alike have had their desire to adopt EVs hampered as a result of "range anxiety"—the fear of running out of charge mid-journey. Recognizing this anxiety, regulators in the US have approved $5 billion for EV charging projects over the next five years and recently allocated an additional $2.5 billion for community chargers. Europe has gone even further, mandating fast charging stations within every 60 km length of major highways by 2026.

The private sector is stepping up its efforts, too. Automakers have gotten closer to convergence on charging standards with several top manufacturers adopting the Tesla connector for their vehicles. Major brands like Walmart, Sam's Club, Comcast, Ikea, Marriott, and Hilton have committed to build tens of thousands of new chargers across all of their properties, in addition to tens of thousands in combined charging station commitments made by BMW, GM, Honda, Hyundai, and Mercedes. Improvements to existing infrastructure are also underway with Tesla promising 40% faster charging through its V4 technology, companies like EVgo launching initiative's to "renew" existing stations, and navigation services like Waze integrating charging locations into its navigation tech to improve peace of mind in trip planning for EV adopters.

Charging Standardization

One of the lingering issues in the development of the EV market has been fragmentation of charging standards. Globally, the Combined Charging System (CCS) has been the prevailing standard, but the North American Charging Standard (NACS)—commonly known as the Tesla connector—has become the standard in North America with Tesla's overwhelming EV market share. This divergence has become more complicated since Tesla began open-sourcing its NACS connector design at the end of 2022, but progress has been made toward cross-compatibility.

Major automakers including Ford, Rivian, Fisker, GM, Honda, Volvo, Jaguar, Nissan, and Mercedes-Benz have pledged to adopt Tesla's NACS connector or offer NACS adapters, making standardization one step closer in the US. Tesla has also begun to expand its "Magic Dock " superchargers in several US states, adding CCS compatibility in much the same way it has had to in Europe. These two developments have not only moved global charging capacity closer to universal compatibility but have instigated a renewed incentive for further charger development.

As EV adoption and universal compatibility increases, the need for charging station capacity intensifies. This opens up a new vector of competition throughout the industry where vendors, partnerships, and entertainment offerings at charging stations may dictate station utilization rates, and innovations like real-time pricing could allow for solar-powered stations to out-compete traditional stations during fluctuations in solar availability.

Redefining the Roadside

The rise of EVs is transforming our roadside experience. Extended charge times have led retailers like Walmart, Ikea, and Macy's to integrate charging tech, turning wait times into retail opportunities. Tesla's drive-in-diner concept provides culinary and film experiences while EVs charge, while Juxta offers autonomous stores at traditional charging hubs.

With the surging EV demand, innovative solutions are addressing infrastructure gaps. Ample swaps batteries in just five minutes. EV Safe Charge is piloting robots to charge vehicles in non-equipped garages. SparkCharge delivers on-demand charging where fixed infrastructure is lacking.

Even in emergencies, adaptations are evident. Apple's new satellite function broadens the coverage for roadside assistance in low-signal areas. Meanwhile, AAA assists stranded EVs with mobile charges and is exploring electric tow trucks for green, on-the-go recharging.

VEHICLE CHARGING SCALES

Electrifying Cities

Accelerating frequency and severity of climate events, along with rising electric vehicle adoption, has seen cities push their electrification strategies to the top of their agenda. On the grid, decentralized energy systems have been a consistent theme. Public utilities like Vermont's Green Mountain Power are installing batteries in customers' homes to ensure power resilience during outages and to optimize costs by utilizing stored resources during periods of low supply or peak demand. In North Carolina, a residential community called Heron's Nest is being developed to include a microgrid independent of the larger grid. Each home includes a solar energy system contributing to a collective network that not only powers the community but ensures its resilience and sustainability.

In transportation, cities like New York City and Los Angeles have considered requiring rideshares to run completely on EVs by 2030. To cope with rising demand for charging in cities, governments are racing to expand capacity. France, for example, is working with Electreon to install wireless charging on its roadways, and the US recently earmarked $25 billion to expand community charging capacity. These actions underscore what is becoming a global shift toward a sustainable and resilient urban future, ensuring cities remain powered, efficient, and ready for the next era of electrification.

EVs At Home

As the EV market has matured, a significant shift has been taking place in the home. On the heels of California's 2020 mandate for solar installations in new homes, Illinois has passed laws requiring new and renovated properties to have at least one EV-capable parking space for each residential unit that has dedicated parking by 2024. A proposal under consideration by New Mexico legislators would go even further, mandating all new homes be constructed with a solar-powered system and EV charger. In Germany, a grant to help fund home-charging installations was tapped out in one day, with over 33,000 people applying just hours after it went live. These regulatory efforts coincide with initiatives from automakers to try to bring chargers to the home. Hyundai, for example, has pushed promotions that would provide a free EV charger and a reduction in installation costs to every new customer.

These efforts to transform have paved the way for more widespread adoption, but the swift transition has also uncovered potential challenges for EVs at home. Surveys by the Electrical Safety Foundation indicate that the electrical systems of over half of US homes may be unable to safely carry the continuous load that EV charging demands. If the rapid adoption of EVs leads to an increase in brownouts, electrical surges, or fires resulting from overloading home electrical systems, more stringent regulations may become more popular for concerned local governments and homeowners associations. Still, forward-thinking communities may use the opportunity to collaborate on more communal solar arrays or shared charging stations, presenting an efficient and cost-effective solution.

Electric vehicles taking advantage of chargers on city streets.

VEHICLE CHARGING SCALES

Bidirectional Charging

Electric vehicles with bidirectional charging capabilities present an exciting frontier. These vehicles can not only consume energy but also supply it for other applications, transforming the traditional role of cars. No longer merely used for transportation, bidirectional EVs now have the potential to energize homes, businesses, and entire communities. With bidirectional charging, owners can strategically charge their cars overnight using affordable grid energy and then utilize the EV's stored energy during high-demand daytime periods, ensuring efficient use of resources. Growing challenges such as the energy crises linked to geopolitical events in Ukraine, escalating climate disruptions across the globe, and widespread concerns around outdated infrastructure and cybersecurity only underscore the timely importance of this technology.

The automotive industry has been quick to embrace this innovation. Ford, Genesis, Hyundai, Kia, Mitsubishi, Nissan, and Volkswagen have all rolled out vehicles with bidirectional charging. GM has gone a step further, declaring that by 2024, vehicle-to-home (V2H) charging will be a standard feature in its vehicles. Other industry leaders like BMW, Volvo, and Porsche are actively testing this technology. Even Tesla, which initially seemed skeptical, has announced plans to incorporate bidirectionality in all its vehicles by 2025.

Municipalities are recognizing the value of this transformative technology in energy management. Utrecht, a prominent city in the Netherlands, stands out in its adoption, actively installing bidirectional charging stations that allow shared vehicles to contribute energy back to the grid. In the US, California is at the forefront, contemplating legislation to make bidirectional charging mandatory for new EVs. The possibilities are vast, and the trajectory suggests a future where our vehicles play an integral role in a sustainable energy ecosystem.

Rendering of the Nissan Vehicle to Home (V2H) System concept

Source: Nissan

IMMERSIVE VEHICLES CONNECT TO OTHER ECOSYSTEMS

Livable Cabins

Auto manufacturers are revolutionizing the way we experience our vehicles. Rather than a car solely serving as an uninspired vessel to get us from one location to another, manufacturers are emphasizing enhancing cabin environments. Now, they're not just for driving but also for riding, relaxing, working, and playing. In many instances, automakers attempt to transform these landscapes through the increased use of screens. In a Peugeot concept called Inception, a screen-supported human-machine interface replaces the traditional steering wheel and displays control information. Continental is also capsulizing on the screen-infused future with its ultrawide In2visible: a touchscreen that spans the full length of the dash resulting in a high-intensity driving experience. Ultimately, such interfaces are intended for fully integrated digital experiences. Chrysler has given its view of a fully electric future where the cockpits of its vehicles integrate Stellantis-branded software, including the STLA Brain operating system, STLA AutoDrive Level 3 driver assist, and STLA Smart Cockpit infotainment system. This connected experience will sync with calendars and smart home data, handle driving tasks within designated areas, and even offer wellness and fun features, like meditation and in-car games. But the proliferation of large and clunky screens is being sharply criticized, as they have impacts on ergonomic, safety, and aesthetic factors. If they continue to grow unchecked, they could ultimately be challenged by regulators. Despite these concerns, as personal mobility is enhanced with longer ranges and increased implementation of autonomous driving features, auto manufacturers will continue to improve comfort within vehicles and engage customers through new onboard touchpoints, impacting how we've traditionally engaged with roadside attractions and amenities.

Simulated Driving Experience

Electric vehicles are known for being incredibly quiet, and some view this as problematic. Specifically, EVs don't make the typical shifting noise that drivers are used to hearing, and this can cause issues by depriving drivers of auditory and even touch-based feedback they are accustomed to. This also affects bystanders. The lack of noise from electric cars contributes to their high rate of accidents: EVs are 40% more likely to hit a pedestrian than a normal car, and for the visually impaired population, this number jumps to 93%.

Toyota is adding audible features to its electric cars—including a simulated gear stick and artificial "noise" simulating a combustion engine—aimed at drivers who prefer a more traditional driving experience. This simulated manual transmission experience might even come with the possibility of stalling in order to retain the charm and enjoyment of driving a manual transmission car. Hyundai and Dodge are also exploring sound design in the execution of their EVs, not just for preference reasons but because the addition of artificial engine noise is also a safety standard, alerting pedestrians to the presence of electric vehicles. Ultimately, some manufacturers are hoping that drivers are more likely to adopt electric cars if they sound and feel just like their gas-powered counterparts, while the inclusion of these simulations is primarily about keeping people safe.

In-Vehicle Connectivity

The role of high-speed, low-latency connectivity is becoming a prominent factor impacting the performance of the vehicle along with the in-cabin experience. While internet access in cars is not new—Starlink currently provides connectivity for Subaru—carriers such as AT&T and Verizon have ambitions for executing on this modality. AT&T, in particular, sees 5G connectivity in conjunction with edge computing as a way to enable new functions and services through this network and cloud convergence. This framework will not only support the safety and mission-critical functions of the car but also intelligent transportation systems, teleoperations,and autonomous driving, along with onboard infotainment systems. More tactically, Verizon launched the Connected Car by Verizon, which offers select BMW models features such as voice, data, and unlimited Wi-Fi hotspot connectivity through subscription. With regards to more tech

IMMERSIVE VEHICLES CONNECT TO OTHER ECOSYSTEMS

demonstrations or spectacles, General Motors collaborated with Etisalat to host a gaming tournament that took place entirely within connected Chevrolet and GM cars equipped with in-vehicle Wi-Fi. The tournament featured 10 gamers who participated in a 12-hour event covering 450 km of roads in the United Arab Emirates, organized by OnStar. Cradlepoint partnered with The University of New South Wales for the Bridgestone World Solar Challenge race, by providing 5G/LTE wireless network edge solutions for the Sunswift 7 solar race car and support vehicles. This technology allowed the team to remotely monitor the car's performance and telemetry data. As connectivity becomes more reliable, more subscription services like Verizon's Connected Car are inevitable, much to the disappointment of most consumers.

Mobile Entertainment Hubs

Vehicles are becoming increasingly equipped with multiple entertainment options for passengers and drivers, including technologies such as immersive audio, large screens, and the ability to stream movies, TV shows,

and video games. While Apple and Mercedes-Benz have enabled spatial audio in vehicles, Jaguar Land Rover is turning to haptics to enhance the music experience. Its "Body and Soul Seat" technology, dubbed BASS, features headrest-mounted membranes and transducers that provide haptic feedback in response to lower frequencies in music—and even offer health benefits through integrated wellness programs. Automakers are continuing to add features to be enjoyed by passengers while they're commuting or charging their EVs. Xperi and BMW have collaborated to use TiVo's video media platform in cars to offer customers access to various video content providers, including linear and on-demand streaming services, covering country-specific content such as news, movies, and media libraries. Polestar's most recent software update, P2.9, includes the addition of YouTube for streaming videos during vehicle charging and a revamped version of Apple CarPlay that allows Maps to be projected onto the instrument cluster. Polestar is also the first automaker to offer Nvidia's cloud gaming service, GeForce NOW,

in its vehicles. The service connects to the cloud to access an extensive gaming library. While the use of these technologies is limited for safety, inevitably, these technologies are intended for broader adoption as we inch closer to an autonomous driving future. Ultimately, these new platforms intend to simplify content discovery and enhance in-car entertainment.

CarOS

As cars become even smarter and offer more immersive experiences, navigational and entertainment systems will continue to evolve, necessitating a holistic and centralized operating system. In the current market, many options are available, developed by both OEMs and technology companies. While tech companies have taken a lead in years past, some OEMs are attempting to regain control. Google is making progress in the automotive industry through Android Auto—an app that operates on the user's smartphone and wirelessly sends navigation, parking, media, and messaging to the infotainment system of the vehicle—and Google Built-in,

which directly integrates Google services within the vehicle. Brands like Chevrolet, Renault, Volvo, Polestar, and Honda are set to showcase features like YouTube available in cars with Google Built-in, gaming with GameSnacks, conferencing with Cisco, Microsoft Teams, and Zoom, and further integration with Google Assistant. General Motors is indexing significantly on Google, and in the process is ditching Apple CarPlay for Android Auto in its upcoming electric vehicles. Relating to OEMs, Swedish EV manufacturer Polestar has teamed up with Xingji Meizu to develop an operating system for its cars in China, as part of Geely Group's strategy to tailor vehicles for the Chinese market. The new system, based on Flyme Auto, will connect with in-car apps and mobile phones, and use the latest smart technologies. Jaguar Land Rover is set to release its new electrical/electronic (E/E) architecture, EVA Continuum, with the help of Continental subsidiary Elektrobit for running its software platform and operating system. This move enables faster development and over-the-air software updates, a strategy that other automakers are also beginning to adopt.

SCENARIOS

What if expanded vehicle capabilities redefine the nature of home ownership?

As younger generations grapple with lower real income, higher housing prices, and an expanded tolerance for remote work, connected vehicles became the new starter home of yesteryear. Risks associated with pandemics, crime, and higher rates of depression drove people out of cities and closer to nature, and their vehicles stepped in as an invaluable resource. Mesh networks of 5G and satellite-enabled internet allow people to work, consume entertainment, and connect with others virtually in the comfort of their vehicle—no matter where it's located. Vehicle cabins are redesigned around sleeping, working, and relaxing, while new features that enable cooking, food storage, and waste management become popular add-ons. AI allows vehicles to assist passengers with daily tasks like cooking food or supporting work, while providing security, health monitoring, and the ability to contact emergency services or autonomously drive the vehicle to receive help during situations of duress.

DATA COLLECTION ENABLES SAFETY AND AUTONOMY

Mobility Simulation

Simulation has become an increasingly ubiquitous component across several areas of mobility and will be a defining characteristic in the development of its future. Tesla, for example, has been relying on its Dojo supercomputer to simulate billions of miles of driving for its autonomous driving software since choosing to rely purely on cameras and neural nets to provide its vehicles with self-driving capabilities. Mercedes has also made simulation more central to its strategy, forming a partnership with Nvidia that only underscores this trend. Leveraging Nvidia's Omniverse Generative AI platform, Mercedes hopes to improve its vehicle designs and craft enhanced driving algorithms by simulating countless potential real-world scenarios, to create vehicles that respond optimally across various conditions.

Universities like Ohio State and the University of Michigan have brought mobility simulation to academia as well. Ohio State, for example, uses simulated environments to test the safety and aptitude of real driverless cars, while the University of Michigan has begun running simulations on historically crash-prone intersections to try and reduce incidents. Globally, the Indian city of Chennai is now using traffic simulation to study and improve congestion within its borders; while academics in Egypt and Brazil are relying on simulation to test and demonstrate new innovations in traffic signal technology. As data abundance exponentially expands, simulation will increasingly be at the heart of mobility design.

Self-Aware Vehicles

Vehicle connectivity is changing the landscape of mobility. The abundance of sensors, monitors, computing power, and network availability has enabled vehicles to provide information and, in some cases, act on it in ways that would have once been considered unprecedented. For example, this year, Goodyear tested its SightLine tires, which can measure tire-road friction, wear, load, inflation pressure, and temperature. Software-enabled vehicles can integrate with and monitor multiple powertrains or propulsion sources, allowing vehicles to reach as much as 1,000 horsepower while maintaining equilibrium to prevent risks like disintegration. Indian technology company Tata Elxsi is developing technologies that would alert automobiles to approaching emergency vehicles, and indicate slippery roads, dangerous curves, and potholes or roads under repair so that they can appropriately adapt to the approaching conditions. Honda and Sony's Afeela cars are being designed to "feel" their driver's moods and allow them to express themselves and interact with others on the road via external screens on the front of their cars. Ford has even patented self-reporting technology that allows cars to lock out drivers, disable features like air-conditioning, restrict driving to only certain hours or locations, and to even utilize self-driving to return cars to an impound lot. As vehicles continue to get more connected and aware, mobility will look strikingly different from the modern day mobility environment as we know it.

Pilot and Passenger Observation

Technological advancements have enabled detailed monitoring of both driver and passenger behaviors, significantly enhancing safety and operational efficiency within vehicles. Safety sensors and equipment are now being built to detect distraction, drowsiness, and substance influence. Smart Eye's Driver Monitoring System, for example, gauges driver attentiveness, providing real-time feedback to prevent mishaps. Similarly, Magna's advanced driver assistance systems use cameras and interior mirrors to identify distracted behavior and try to reduce accidents. In the US, the government is pushing to require in-vehicle breathalyzers by 2026 so that drivers under the influence cannot take the wheel until the vehicle confirms their capacity to wield it responsibly. As vehicles gain more ability to observe and control those within them, entirely new privacy and data security concerns are emerging. With monitoring systems becoming more common in standard vehicle requirements and designs, a balanced framework that addresses both safety enhancements and privacy concerns will become crucial for

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getting the best out of these technologies.

Mobile Weather Stations

The Mobile Weather Station (MWS) has become a crucial instrument for the real-time monitoring of weather and environmental conditions, offering granular insights crucial for sectors like transportation, agriculture, and emergency response. While universities across the United States, along with companies like Verizon, are creating some of the technologies that enable the stations, several states and municipalities are using them to bring about improvements across their domains. For example, in New York City, the FloodNet Initiative utilizes MWS to monitor water levels, predict flooding events, and optimize drainage systems to minimize potential damage to the metropolitan area. In California, MWS is being used to detect early indicators of potential wildfires and changes in algae levels that can ultimately save lives and preserve ecological health. In Connecticut, MWS was introduced to gather air pollution data to ensure public health and enforce breaches in regulatory compliance.

As drones, cameras, sensors, meteorological instruments, particle detectors, mobile networking, and high precision GPS technology continue to improve, expect to see the MWS become more ubiquitous across the US.

Mobility Superapps

Superapps are emerging as a powerful force, amalgamating various transportation services into a singular mobile platform, and subtly changing the mobility landscape for governments, businesses, and consumers alike. They embody a convergence where ride-hailing, public transit, and even non-transportation services harmonize, offering a seamless user experience. Leading this transition are companies like Uber and Grab. For example, Uber's ambition extends beyond ride-hailing; in the UK, its app integrates bikes, scooters, trains, buses, and even planes, aspiring to set a precedent in global mobility solutions. They're not just about consolidating services for consumer convenience but also about orchestrating a smarter, sustainable urban mobility framework. And with every transaction, Uber gath-

ers invaluable data that enhances the user experience in addition to providing insights that can inspire better urban planning, public transit, and infrastructure decisions by local governments. Companies across Asia and the Middle East have already proven the viability of superapps, but now US mobility and technology companies are striving to be the first to make superapps the norm domestically.

Utilizing Mobility Data

Mobility data has become a pivotal asset in modern transport dynamics. Real-time monitoring and analytics, combined with geospatial data, enables companies to harness spatial information to create and enhance products and services across the mobility spectrum. New open map data sets like what are provided by the collective efforts of Amazon, Microsoft, and Meta add to the map data already offered by Apple and Google; this additional competitive pressure will likely lead to further innovation across the space. More widespread availability of data and analytics has also allowed companies

like Uber and Lyft to leverage mobility data to pinpoint underserved areas and identify burgeoning potential for new markets or services. This data can also help automakers and municipalities identify optimal locations for charging stations or micromobility docks, to effectively spread charging capacity and achieve optimal utilization. Richer mobility data can also lead to improved regulatory efforts. For instance, data insights can help inform regulations for autonomous vehicles and ride-sharing frameworks, and potentially become the catalyst for standardizing data-sharing protocols among mobility providers. As the investment in and availability of mobility data continue to grow and the sources for collecting the data expand, a future where mobility solutions are seamless, efficient, and tailored to individual needs will start looking like the norm.

Relying on ADAS

As the auto industry continues to push toward fully autonomous self-driving, advanced driver assistance systems (ADAS) are giving drivers a glimpse of what that future might look like.

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New vehicles are increasingly coming with automated technology to monitor blind spots, stay within lanes, parallel park, and trigger automatic emergency braking (AEB). The driver's experience is evolving, with ADAS reducing the manual load, creating a more relaxed yet controlled driving environment. Estimates suggest that ADAS implementation has the potential to prevent up to 250,000 deaths between 2021 and 2050, not only saving lives but likely also reducing insurance and health care costs . On the regulatory front, regulators are already proposing stricter requirements for AEB to mitigate high-speed collisions and better protect pedestrians and drivers. Looking ahead, ADAS applications will continue to expand. Advancements like adaptive cruise control and intersection assist can further mitigate risks and improve traffic flow. Several collaborations are taking place across the industry to make these systems a reality. Porsche and Mobileye, for example, are pushing the boundaries, developing systems capable of full collision avoidance and other sophisticated functionalities. Such advancements portend a future where features of these kinds are the standard and hopefully driving is safer, more accessible, and economically beneficial as a result.

Pedestrian Concerns

The advent of autonomous vehicles (AVs) and micromobility solutions like e-scooters and e-bikes in urban landscapes has triggered a cascade of pedestrian concerns. In Austin, Texas, complaints are rife about dangerous encounters with AVs, one notable incident being a Cruise vehicle veering off-road into a small building. Similarly, in San Francisco, robotaxis have been reported blocking traffic, obstructing emergency vehicles, and causing nuisances. The micromobility sphere isn't devoid of issues either; e-scooters and e-bikes have been associated with injuries, like in incidents reported where riders navigate recklessly amid pedestrian traffic or lose control, leading to accidents. Research from the US Consumer Product Safety Commission shows that micromobility incidents increased by 21% year over year in 2022, as e-bikes, e-scooters, and hoverboards grew more popular.

These real-world incidents have spurred a mix of public, regulatory, and commercial responses. In California, legislation requiring safety operators on autonomous trucks was a notable step toward ensuring safer road interactions, but in San Francisco, the expansion of driverless taxi services has prompted protests by city officials and civic groups. Commercial entities are also pitching in; Cruise officials in Austin have been training first responders to foster safer interactions with their AVs. As AVs and micromobility solutions continue to meld with urban mobility, addressing pedestrian safety concerns through a combination of legislation, community engagement, and technological advancements will be paramount.

AV Viability

Autonomous vehicles are making major strides in capability and level of adoption, but full self-driving still remains far out of reach. Most come standard with autonomous features that keep them in lanes and cause them to brake automatically, and features that allow automobiles to autonomously change speeds, change lanes, and take advanced actions like parallel park are becoming increasingly common. Mercedes has begun to test Level 3 autonomous driving, and more major auto manufacturers are slated to begin testing their Level 3 vehicles in the coming years. Some AV software developers have been testing robotaxi services in select municipalities, with some going as high as Level 4 autonomy. Meanwhile, several auto manufacturers have started adding features and services to their vehicles to facilitate productivity and entertainment for passengers in anticipation of autonomous driving freeing up drivers' attention. Yet several major hurdles remain for Level 5 autonomy. Some friendly legislators have resisted pressure from stakeholders like truckers and pedestrians, giving AV manufacturers some breathing room to begin testing and rolling out their vehicles. But federal legislation to address the topic has been stuck in Congress for six years with no signs of life. With challenges that include safety concerns, cybersecurity threats, insurance liability risks, and questions regarding infrastructure readiness, privacy protection,

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and ethical frameworks to dictate how AVs make decisions in trade-off situations, full implementation faces many major hurdles. That's why Ford, for example, stopped developing full self-driving in favor of nearer-term goals like Level 3 and Level 4 autonomy. What's clear is that whether it's full self-driving or not, autonomy is here to stay.

Local AV Regulations

As vehicles become more sophisticated, adding semi- or full-autonomous features, local governments must determine when and how to authorize their use within city limits. Many local governments and business communities eye autonomous vehicles as an engine for economic growth. Cities and states are exploring new ways to integrate autonomous vehicles into their longer-term planning. Phoenix and Los Angeles, among other cities, are developing innovative approaches to designing, building and testing autonomous vehicle systems. Several states and cities are considering legislation to help bring the technology to market. But regulations intended to spur development could hit a roadblock—city and

state governments control their local streets, but the federal government regulates surrounding highways; for autonomous vehicles to become ubiquitous and practical, America's roads would need to be interoperable.

Robotaxi Growth

Robotaxis are undergoing significant testing and deployment across numerous US cities, with 23 states having enacted laws permitting companies to do so. Moreover, at least eight other countries in Europe, Asia, and the Middle East have embraced the robotaxi revolution through testing and operations. Operating up to Level 4 autonomy, robotaxis primarily function within geofenced urban areas that are well-mapped, characterized by slower speed limits, and highly trafficked, which provides ample data for system refinement. Robotaxis have now amassed several million miles, and over 100,000 users wanting to experience a robotaxi service are still on Waymo's waitlist alone. Although assertions that robotaxis are safer than human-driven vehicles may be premature pending more extensive service

miles, the initial results are encouraging. Yet, challenges persist. Cruise, projected to incur over $2 billion in losses in 2023, has been striving to extend service hours and geographic coverage to bolster revenue and meet the high demand. The rollout of robotaxis in Texas and California has also spurred public protests, especially following a series of incidents relating to traffic congestion and safety. And despite a string of approvals to expand service in California, the state's DMV recently moved to suspend Cruise's permits following a number of new incidents. Concurrently, a lawsuit challenging the regulatory body overseeing robotaxi deployments in the state has started to gain traction, and federal authorities initiated a probe into Cruise's safety practices during its operational rollout. To achieve broader public acceptance, autonomous vehicles will need to demonstrate markedly better safety outcomes when compared to human drivers. The enthusiasm from manufacturers and municipalities to expedite robotaxi adoption globally is palpable, yet public apprehensions and the accident incidence rate during

the testing phase will influence whether the pioneering companies can achieve substantial testing benchmarks to draw meaningful comparisons with human drivers, and the time frame required to reach this goal.
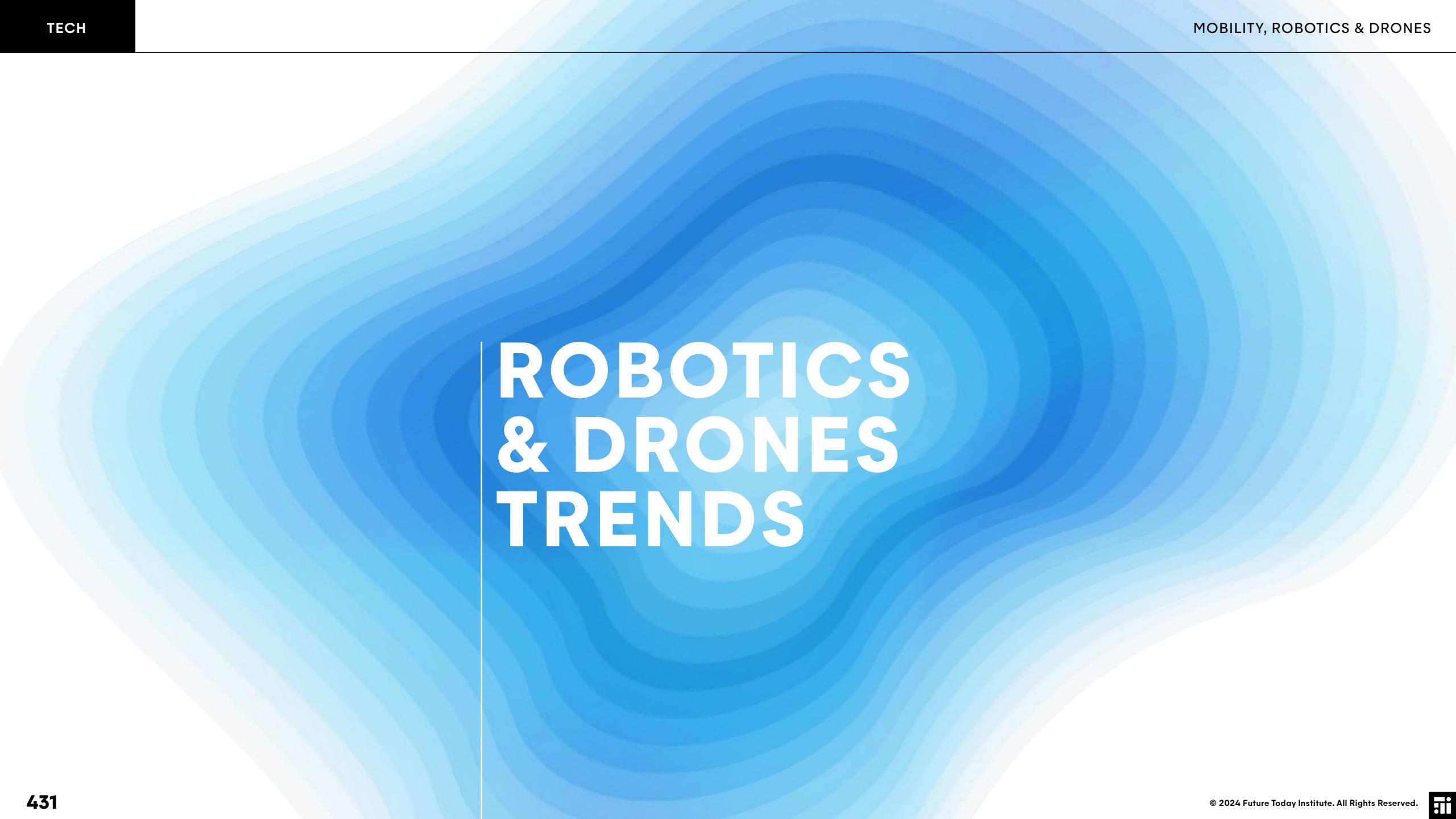
SCENARIOS

Personal Everything Mobility Platforms

While superapps were ubiquitous in Asian countries as early as the 2010s, they didn't gain momentum in North America until the mid-2020s. The movement began when Elon Musk pushed for X to become the everything platform, but his vision did not come to fruition after the company failed due to advertising conflicts and users abandoning the platform. Instead, where everything platforms began to gain traction was in the travel and mobility industries. While there's still competition among these platforms to avoid antitrust laws, one particular platform has risen to prominence: OmniMoble, which successfully aggregated many major touchpoints and access points for an individual's comprehensive mobility needs. By fully integrating into users' schedules, the platform removes most frictions, frustrations, and hurdles that present themselves in the tediousness of everyday life. Now, when a user is told to go on a business trip, OmniMoble will recommend, unprompted, available livery, flight, and hotel options, accounting for both her personal preferences and company allowances. Once she's presented with options meeting those criteria, the user can make her selections with minimal effort. On the day of travel, she boards her flight with ease. However, while on her flight, she realizes she didn't pack a belt for her business attire. From the plane, she consults OmniMoble, and it provides available options closest to her hotel from her favorite designers. Before landing, the belt is delivered to the hotel.

ROBOTICS & DRONES TRENDS

COBOTS BECOME COWORKERS

Accelerated Adoption

Cobots serve to supplement or even replace workforces, especially those constrained by labor shortages. This evolution is already happening in Japan, which is in the midst of a significant demographic shift, as the working-age population begins to decline. The resulting extreme labor shortages are causing industries in Japan to turn to increased cobot usage, but the country is also able to undertake this endeavor because of a highly computer-literate workforce. With a strong knowledge base for mechanical and control systems and IT skills to manage the cobots, companies are supplementing more workplaces with these bots—and also improving productivity in the process. In one example, Fujita Works has successfully incorporated cobots in welding processes, reducing the time required to master welding techniques. In a broader geographic lens, cobots are expected to have a tremendous impact on the future of work. According to Grand View Research, the collaborative robot market is expected to grow by more than 30% by 2030, reaching a value of $11.04 billion. Cobot adop-

tion is also being driven by major players, as Amazon seeks to expand its robotics operations at fulfillment centers with updated sorting machines, robotic arms, and mobile robots. This new system, Sequoia, is intended to work in collaboration with humans and is expected to increase delivery fulfillment speed by 25%. Amazon contends that this increase in speed will not be at the cost of eliminating humans from the workforce. Whether or not that turns out to be true, the inclusion of new bots in the workforce will likely have at least one positive outcome for human workers: They increase safety and reduce human injuries.

General Purpose Robots

Versatile, general purpose robots are the holy grail of robotics, promising bots that do not have to be limited or pigeonholed into single categories but can be used for vast and diverse purposes without requiring extensive calibration between disparate tasks. Several robots are in the works that may bring this kind of general purpose robot closer to reality. One, from startup Figure, is a versa-

A "Digit" robot working in an Amazon fulfillment center.

Source: Amazon

COBOTS BECOME COWORKERS

tile, bipedal humanoid robot that can perform a range of tasks, from manual labor to eldercare. Figure has raised $100 million and hired top talent from leading tech companies, including Boston Dynamics, Apple, Google, and Tesla. Its plan includes an unveiling of the robot this year, with a starting focus on warehouse and retail applications and potentially a robotics-as-a-service (RaaS) leasing model. Tech startup Sanctuary AI is pursuing a similar model, and has created a humanoid robot named Phoenix that can perform a variety of workplace tasks. Standing at 5'7" and weighing 155 pounds, Phoenix is equipped with advanced sensors and human-like hands with haptic sensors that enable it to carry out precise tasks. The robot is powered by Sanctuary's AI control system, Carbon, which can be trained to learn new tasks either by simulation or human demonstration. But in order for general purpose robots to succeed, real-world and simulated training data is necessary to teach bots to adapt to various tasks. RoboCat, a self-improving AI agent for robotics, attempts to do just that. In as few as 100 demonstrations, it can operate various robotic arms and learn to perform different tasks. RoboCat's approach accelerates robotics research by reducing the need for human supervision, bringing us closer to versatile, general purpose robots.

Robots in the Home

The landscape of domestic robotics is transforming homes into hubs of automation, easing daily chores and offering companionship. For instance, robotic vacuum cleaners have become household staples, tirelessly navigating living spaces to keep them dirt-free. Similarly, robotic lawn mowers now keep lawns well-trimmed without the sweat, while robotic pool cleaners keep swimming areas sparkling day or night. As artificial intelligence has permeated these robotic devices, their ability to recognize voice commands, integrate with smart home ecosystems, and operate with minimal human intervention has made a significant stride for at-home robotics and automation. More recently, however, robots at home are becoming hubs for companionship. For instance, ElliQ, an AI-powered companion robot, is bridging the emotional gap for seniors, offering friendly interaction and ensuring their safety. The robot proactively engages in conversation, offers medication reminders and issues emergency alerts; these aren't just features but a leap toward combating loneliness among the elderly. Robosen's Grimlock transformer toy similarly provides companionship, but for kids and young adults. Their toy not only transforms but is capable of understanding a variety of commands and can communicate with those who play with it. In what is maybe the most extreme example of robotic companionship, individuals known as iDollators are even using AI-augmented synthetic dolls to form sexual relationships at home. And with new ideas like Bopeep's robotic furniture—carefully designed to overcome robots' typically overbearing presence—or old ideas brought to life like Prosper Robotics' robot butler, efforts are underway to blend household capabilities and companionship together. The fusion of AI with robotics is blurring the lines between the mechanical and the emotional, pushing the boundaries of what robots can offer in the home. As technology continues to evolve, the role of robots is set to expand, heralding a future where our domestic companions are not just helpers but friends who share in our daily lives.

Robots Coexisting with Creative Applications

The field of robotics continues to demonstrate how possibilities are endless for application. In Switzerland, AI-powered robots are now acting as security guards where their surveillance capabilities and real-time response mechanisms are improving safety without the need for human intervention. South Korea witnessed a remarkable blend of art and robotics with EveR 6, a robot conductor that fuses music and technology, broadening the horizon of what robots can achieve in what are typically viewed as human-centric creative domains. In the US, robots designed to handle hazardous materials were able to execute a mission to safely dispose of chemical weapons, reflecting a crucial application in high risk environments. In education, hundreds of kindergarten classes are now using a small robot named KeeKo, which tells stories, poses

COBOTS BECOME COWORKERS

logic problems, and reacts with facial expressions when students master content. Scientists at MIT are using a teddy bear robot named Tega to improve the language and literacy skills of 5 and 6-year-olds, and have so far seen positive results. While these are just a few disparate examples among many, the versatility of robotic applications already appears endless, and the plethora of possible uses for the technology will likely only grow from here until robots become ubiquitous across our everyday experience.

Space Robots and Drones

Space exploration has long been an area that has embraced robots and drones. This technology is central to space exploration's mission; without them, exploration of harsh and distant environments would be impossible. Currently, NASA's Astrobee smart robots, operating aboard the International Space Station (ISS), underscore the role of robotics in aiding scientific research and routine maintenance in space. These cube-shaped robots, capable of free flight within the ISS, allow astronauts to offload mundane tasks, freeing them to focus on more critical, human-centric activities. While most people know about NASA's Mars Rover, NASA's Ingenuity drone has been testing off-earth flight, recently registering one of its longest flights. There are also several recent examples of new applications for space robotics and drones being developed for space. On the orbital front, ClearSpace, a Swiss space company, is pioneering efforts to mitigate space debris. With its ambitious ClearSpace-1 project, the company is building a claw-like spacecraft capable of capturing and deorbiting space junk, marking a significant step forward in cleaning up Earth's orbital environment. At MIT, researchers are testing modular lunar robots, equipped with flexible robotic arms resembling worms, showcasing how innovative approaches are being adopted to navigate and interact with extraterrestrial terrain. Another project by ETH Zurich has been exploring how quadruped ANYmal robots have the potential to exhibit robotic teamwork in executing lunar missions, such as material harvesting for base construction. Similarly, GITAI is building robotic rovers and arms with the goal of creating an autonomous labor force for the moon and Mars to reduce space labor costs. Further extending the capabilities of space robots, NASA's Goddard Space Flight Center is developing OSAM-1, a satellite repair robot aimed at prolonging the operational lifespan of satellites. This initiative heralds the onset of in-orbit servicing and manufacturing, which could revolutionize space infrastructure management. The various projects and technologies in the realm of space robots and drones exhibit a confluence of robotics, aerospace engineering, and collaborative endeavors, driving forward the frontier of space exploration and habitation enabled by advances across drones and robotics.

ETH Zurich's modified quadruped ANYmal robots.

Source: ETH ZURICH / TAKAHIRO MIKI

ROBOT AND DRONE INFRASTRUCTURE

Robot Compiling and Training

Virtual training harnesses the power of AI, simulation, and digital twins to propel the capabilities of robots and drones to new heights. Nvidia, in particular, has been a leader in this space. The company's Isaac Sim and Isaac Gym platforms simulate 3D physics in video game–like environments, allowing for parallel training sessions across numerous virtual realms, thus significantly reducing robot and drone training time. A collaboration from Nvidia, UPenn, Caltech, and the University of Texas at Austin known as Eureka showcases this by making use of OpenAI's GPT-4 to design and refine training goals. It then runs through parallel simulations in virtual environments to help robots learn complex tasks virtually before transitioning to the real world. Toyota's AI robot recently showcased the ability to master complex tasks in a matter of hours, again highlighting the accelerated learning curve that comes from virtual training. Digital twins are also being used to help autonomous robots and drones improve their path-planning by navigating through various environmental conditions safely and effi-

ciently in virtual space. They can even help train robots to pack objects into tight spaces, as was shown by MIT, which developed a technique to use virtual environments to improve robots' ability to optimize space utilization. In anticipation of robots and drones working together in reality, Nvidia's robot simulator recently gained the ability to simulate human co-workers as well, mimicking real-world scenarios to improve robot-human interactions. This evolution in digitally enabled training not only promises a future of highly skilled robots and drones but also hints at a paradigm shift in how training and development in the field of robotics and drones are approached and the potential for much more rapid development across the space in the future.

Robot and Drone Swarms

Drone swarms, made up of groups of drones functioning as a collective unit, unlock capabilities far beyond the reach of individual drones. Despite their first commercial use-case coming in the field of entertainment as a fireworks alternative for complex light

displays, their breadth of applications have significantly expanded. The US and Chinese governments have shown a keen interest in using drone swarms across their militaries, leveraging them for surveillance, tactical engagements, and logistical support. The agricultural sector stands to gain too, with promising applications in pest control, monitoring, and harvesting, which are ripe for disruption by drone swarms. The technology is also expected to highly impact emergency response: sensor-equipped swarms can offer invaluable real-time information and assistance during natural disasters or search-and-rescue missions. However, the path to wider adoption faces challenges. Real-time data processing, communication, and decentralized control algorithms limit current drone swarms to applications with limited need for adaptability due to the current requirement for extensive preprogramming to effectively use them. The research community is actively tackling these issues. The University of Houston is exploring algorithms for better swarm control, while MIT is developing WiSwarm, a novel algorithm

facilitating the management of high loads of time-sensitive data. As the technology overcomes these technical hurdles and continues to capitalize on emerging applications for the technology, drone swarms are poised to have a transformative impact across various domains.

Drone Fleets

Drone fleets are steadily gaining traction as companies seek to enhance operational efficiency, reduce delivery times, and minimize human intervention. Amazon, for instance, has been testing prescription deliveries via drones in College Station, Texas, with turnaround times guaranteed to fall within an hour. This venture not only expedites delivery times but also caters to immediate medical needs, marking a leap toward on-demand health care services. Similarly, Uber unveiled plans to deliver Uber Eats orders via drone, though not direct to customers' homes but to designated locations for final delivery by drivers. This hybrid model could significantly reduce meal delivery times. Wing, a subsidiary of Alphabet, is on a trajectory to handle tens of millions of

ROBOT AND DRONE INFRASTRUCTURE

deliveries for millions of consumers, show-casing the potential scale possible with drone delivery services. The collaboration between Wing and Walmart to offer 6-mile drone deliveries over Dallas is a testament to drones' potential to revolutionize retail logistics. FedEx, too, is exploring autonomous drone cargo transports, hinting at a future where intercity cargo transport could be drone-driven. On a larger spectrum, Saildrone and the National Oceanic and Atmospheric Administration have collaborated to deploy sailboat drones to monitor climate change's effects on oceans; this kind of use unveils a broader scope of drone applications beyond aerial vehicles. The infusion of drones in these diverse domains underscores a promising potential for automated, efficient, and perhaps, more environmentally friendly operational frameworks that could come from the use of drone fleets. As regulatory landscapes evolve to accommodate drone operations, the horizon seems expansive for drone fleets, potentially altering the traditional contours of service delivery and environmental monitoring.

Drone Traffic Management

The escalating use of drones necessitates advanced traffic management solutions to ensure safe and efficient operations. In the US, the Federal Aviation Administration, partnering with NASA and other bodies, is pioneering Unmanned Aircraft System Traffic Management (UTM) initiatives to oversee low-altitude drone operations. In 2023, they unveiled a UTM implementation plan that includes, in the short term, devising essential protocols and infrastructure, alongside long-term goals like enabling real-time airspace status updates and achieving full operational capability for routine beyond visual line of sight (BVLOS) drone operations. In India, the rise in drone activities has fueled the need for sophisticated UTM systems, leading to a goal of managing a daily drone fleet of 10 million by 2030. Conventional aviation traffic management, dependent on communication between pilots and air traffic controllers, is inadequately equipped to handle the burgeoning drone traffic. In contrast, UTM systems, with their digital interfaces

and real-time communication capabilities, are poised to diminish communication lags and effectively oversee drone operations. Initiatives are also underway in New York, Oklahoma, and the UK to designate specific airspace corridors exclusively for drone operations. Notably, the UK's Project Skyway aims to establish a 265 km UAV corridor by 2024, marking a significant stride towards BVLOS drone operations. Concurrently, MIT has developed an algorithm centered on real-time path planning, which could be assimilated into UTM systems to help drones dynamically adjust their paths, avoiding midair collisions. Collectively, these advancements highlight the evolving realm of drone traffic management, each contributing uniquely to fostering safe and proficient drone operations.

Rendering of Altitude Angel's ARROW technology enabling the UK's Project Skyway.

Source: Altitude Angel

SCENARIOS

Drone Harvests

Over the years, drones aided precision agriculture by planting seeds, assessing crop health, and using targeted pesticides. These integrated units have worked remarkably well to boost crop yields. But now, drones are even able to manipulate the weather. During the early 2020s, researchers discovered that drones could target specific clouds and use lasers to trigger rainfall by forcing water droplets to pool in the air. By the turn of the decade, this practice gained awareness, and precision ag startups began experimenting with it. Through such systems, farmers gain even more control of the crop harvesting process by manipulating the weather with drones after conducting health analyses on crops. They also benefit by being able to supplement irrigation systems and reduce associated costs. But, not surprisingly, much controversy has surrounded this new practice, as regulators are concerned with the possible larger implications this process has on the environment. While these concerns persist, there's currently no effective way to limit the activity, and regulators are working diligently with precision ag startups and farmers to better monitor its use.

MOVING PEOPLE, PETS AND OBJECTS

Last-Mile Delivery

Delivery robots and drones are significantly altering the logistics paradigm for last-mile delivery. Companies like Uber Eats have forged partnerships with Serve Robotics to begin bringing autonomous food delivery into the mainstream, though not without hurdles. Recent incidents of vandalism against delivery robots highlight the operational challenges and financial implications faced by ventures diving into this arena. However, the convictions of several people for incidents caused to delivery robots in LA, along with Serve's claimed 99.9% delivery success rate, give reason for hope. On the aerial frontier, drone delivery enterprises Zipline and Wing have built sophisticated delivery systems indicating an operational readiness to tackle the US market. The trajectory of commercial drone deliveries is notable. As of the first half of 2023, approximately 500,000 commercial deliveries have already been made, and progress doesn't appear to be slowing down. Walmart, for example, has established drone-delivery hubs across seven US states, partnering with companies like DroneUp, Flytrex, Zipline, and Wing

to make drone delivery a key component of its last-mile delivery strategy. The regulatory landscape is also evolving to make drone delivery a more tangible reality. The FAA's BVLOS initiative allows for drone delivery operations under specific conditions at seven test sites. As these regulatory frameworks coalesce, the ensuing cost advantages and sustainability benefits are making drone delivery an attractive proposition for a variety of industries. Food delivery companies like Uber Eats, DoorDash, Domino's, Starbucks, Taco Bell, Papa Johns, Wendy's, and KFC have all begun exploring the technology; retailers like CVS, Amazon, Walgreens, GNC, Walmart, T-Mobile, and Tesco have begun testing or forming partnerships in the space. Even parcel delivery companies like UPS have started drone delivery trials. The ongoing exploration by mainstream retailers, combined with emerging regulatory standards, is not only pushing the envelope for what's possible in last-mile delivery but setting the stage for an exciting era where drones and robots could become a regular facet of the logistics and delivery industry.

Expanded Payload Capacity

Increasing payload capacities and extending flight distances are pivotal in accelerating the adoption of drones across sectors. In last-mile delivery, Alphabet's Wing has increased its drone's capacity to carry up to 7 pounds, a significant upgrade from its flagship drone's original 2.5-pound capacity. In the heavy-lift area of drone development, Elroy Air has showcased plane-like drones capable of transporting up to 700 pounds of cargo across 300 miles. This development could redefine how goods are transported, especially in remote or disaster-stricken areas where conventional delivery systems are unviable. In China, Northwestern Polytechnical University has built bionic drones that can fly continuously for over three hours. And while their exact range of expansion capabilities is still an open question, hydrogen fuel storage systems being developed for drones through a collaboration between Honeywell and the US Department of Energy hold the potential to dramatically increase capacity. Regulatory frameworks are also evolving to accommodate these advance-

ments. The FAA recently granted licenses for unmanned commercial drones to operate beyond a pilot's sight, opening the door for more commercial attempts to push the limits of drones. Attempts include Valmont's joint trial with T-Mobile, where Valmont's drone set a record for a BVLOS operation, covering 237 miles in a single flight. In the military domain, Iran recently unveiled a long-range drone, with the ability to cover distances of 1,240 miles and up to 24 hours of operation—double the distance of the Mohajer-6 drone, which the US has accused Iran of supplying to Russia in its war with Ukraine. While Iran claims its new drone is the longest range drone in the world, that's unlikely to be the case: Drones publicly known to be in operation by the US, including Ultra LEAP and and Global Hawk, have shown an ability to fly for over two days straight, and experiments conducted by the US Army using Airbus' Zephyr 8 drone have been able to stay in flight for up to 62 days straight using solar energy to sustain operation. These developments collectively showcase the vast potential for drone technology, where increased payload capacity and longer flight durations

MOVING PEOPLE, PETS AND OBJECTS

can push the boundaries of what's possible in both existing as well as unexplored domains.

Flying Taxis (eVTOLs)

The realm of urban air mobility is buzzing with the promise of electric vertical takeoff and landing (eVTOL) aircrafts, often referred to as "flying taxis" or "air taxis." Like helicopters, these vehicles are capable of taking off and landing vertically, but unlike their predecessors, they leverage electric power, significantly reducing their environmental footprint. Companies and governments are undertaking several initiatives throughout the US and the globe to make this new form of transportation a reality. New York, California, and Utah have all begun projects in this space. In partnership with Delta Air Lines, Joby Aviation is building vertiports to support a future where passengers transfer from flying taxis to their flights at New York's JFK airport and Los Angeles' LAX airport. Utah released a report outlining plans for the rollout of vertiports across the state, leveraging underutilized parking lots as potential vertiport sites. Meanwhile, globally, Archer Aviation recently

announced plans to introduce eVTOLs to the UAE by 2025, and Paris is gearing up to introduce the world's first electric air taxi network for the 2024 Olympics in partnership with Groupe ADP. Meanwhile, China's Ehang gained approval to start operating its EH216-S autonomous air taxi, capable of carrying two passengers or 600 pounds of cargo over a flight range of 18 miles at speeds up to 80 mph. As the regulatory frameworks evolve and public acceptance for the technology grows, the skies of urban landscapes may soon be dotted with eVTOLs, heralding a new era of urban air mobility. The collaborative efforts among aviation companies, regulatory bodies, and city administrations are fueling the momentum toward making air taxis a reality, promising a blend of innovation, convenience, and sustainability in urban transportation.

Ocean-Faring Drones

Ocean-faring drones, comprised of both unmanned surface vessels (USVs) or autonomous underwater vehicles (AUVs) are changing the nature of exploits across the seas.

Commercially, Yara Birkeland is a pioneering project developed in Norway by Yara International and Kongsberg Gruppen, pushing the boundaries in autonomous shipping. Their vessel is designed to operate initially with a reduced crew, gradually transitioning to fully autonomous operations using sensors, radar, and cameras, paired with artificial intelligence. On the scientific front, innovative projects like the University of Bremen's TRIPLE (Technologies for Rapid Ice Penetration and subglacial Lake Exploration) are using AUVs to probe beneath Antarctica's ice shelves and potentially explore even alien marine ecosystems on icy moons like Jupiter's Europa and Saturn's Enceladus. Militaries are also exploring these technologies. The US Marine Corps, for instance, is testing a drone boat designed to transport loitering munitions for precision strikes and act as a reconnaissance platform for surveillance and intelligence. Recently, ocean-faring drones have even been utilized by Ukraine to target military ships and Russian naval bases throughout their military conflict. While the upfront costs associated with the

development and procurement of ocean-faring drones can be substantial, their long-term benefits are compelling. Reduced human risk, operational cost savings, and the ability to conduct missions in challenging or previously inaccessible environments underscore the transformative potential of these autonomous maritime assets. As the technology matures and regulatory frameworks adapt, the horizons of what's achievable on and beneath the world's oceans are set to expand significantly, heralding a new era of maritime exploration, commerce, and security.

BLURRING THE HUMAN-MACHINE LINE

Natural Exoskeleton Movement

For individuals hampered by limited mobility or injuries, exoskeletons can help. This past year, the FDA cleared Wandercraft's Atalante exoskeleton for stroke rehabilitation in the US. The self-balancing and battery-powered device assists in gait training and helps individuals regain their walking abilities. Ekso Bionics, which has been optimizing exoskeleton bionic devices since 2005, used its technology to assist a paralyzed community college graduate from Virginia to walk across the stage at his graduation ceremony. While exoskeletons have traditionally been large and bulky, researchers at the Swiss Federal Institute of Technology are turning to fiber-like pumps that employ high-pressure fluidic circuits that can be woven into fibers and maybe even into future clothing. This form factor would allow for less cumbersome textile-based exoskeletons that can enable muscular support, thermoregulation, and haptic feedback. In an alternative fashion, researchers at Lausanne University used brain implants to assist a paralyzed patient with walking. The implants wirelessly transmitted the patient's thoughts to his legs and feet through a second implant on his spine, and movements were assisted with an exoskeleton. This, in conjunction with smaller exoskeletal form factors, provides innovative solutions for improving conditions for those with limited mobility.

Superhuman Abilities

Exoskeletons can not only enhance worker performance in industrial settings but also impact athletic performance. Researchers at Virginia Tech's Department of Industrial and Systems Engineering are looking into the effectiveness of exoskeletons in real-world construction applications, postulating that they have the potential to significantly reduce the risk of back injuries and shoulder problems. The robotic exoskeleton startup German Bionic has showcased two products: the Apogee and the Smart SafetyVest. The Apogee assists workers by offsetting up to 66 pounds of load on the user's lower back while the Smart SafetyVest can monitor the wearer's movements and body positioning, providing ergonomic insights, assessments, and recommended actions. While these technologies can be used to ease the burden of repetitive tasks associated with the logistics, construction, and health care industries, some worry that corporations might use the devices to exploit workers with increased output and working hours. Besides job-related tasks, researchers from Chung-Ang University in Seoul, South Korea, have developed a wearable exoskeleton that enables runners to run 0.97 seconds faster by assisting with acceleration and hip extension through electrical motors.

Personal Mobility

Robotics has the opportunity to be an incredible democratizer, capable of supporting, supplementing, and enabling mobility for individuals with mobility impairments. Control Bionics is an Australian company that specializes in advanced assistive technology. It recently developed a wheelchair module called DROVE, which uses AI to enhance mobility for individuals who cannot use traditional steering systems, such as joysticks, due to conditions that affect hand function. DROVE is equipped with a wheelchair-mounted digital camera system, the NeuroNode interface, and home sensors for precise navigation, enabling users to move independently within their homes. Labrador Systems, a California-based technology company, recently launched a new product named Labrador Retriever. It's an autonomous personal robot that can assist individuals with mobility impairments in carrying items around their homes. Users can place items on the robot, and instruct it to move to specific locations through a touchscreen or voice commands. They can also program it to navigate between predefined "bus stops" located within the house. Researchers from Stanford's Biomechatronics Laboratory are taking more of an assistive approach, having developed an exoskeleton that provides personalized assistance to improve limited mobility. The exoskeleton is not designed to walk for the user. Instead, it helps to decrease resistance and friction, thereby enhancing walking speed and energy efficiency. In testing, users reported a 9% increase in walking speed with a 17% decrease in energy used. Ultimately, these

BLURRING THE HUMAN-MACHINE LINE

types of applications empower users by giving them back their independence, comfort, and control.

Humanoid Robots
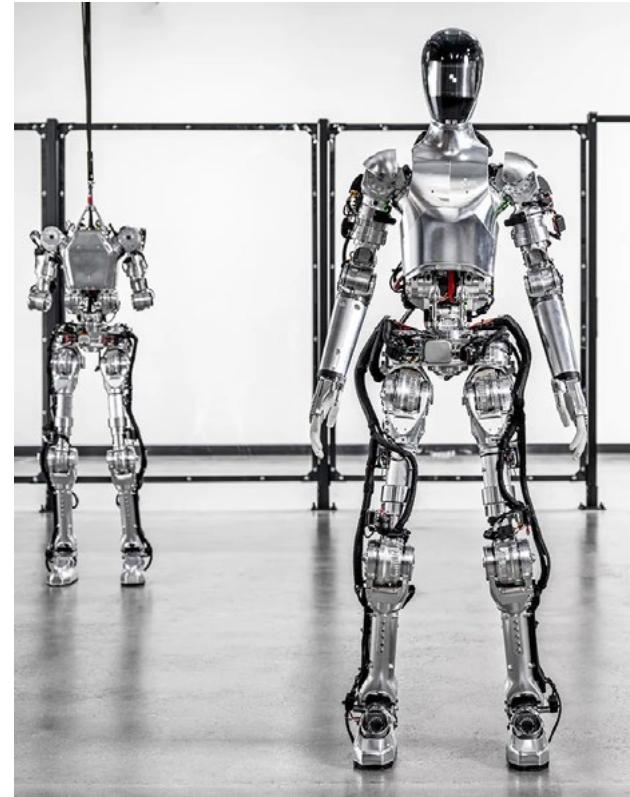
Various companies and startups have made significant advancements in developing robots that mimic the abilities and activities of humans. While initially rudimentary in execution, these humanoid robots are becoming more capable and graceful by virtue of advancements in computer vision, machine learning, and more power-dense batteries. In most instances, these robots are intended to address the challenges of labor shortages and high turnover in many different industries. Tesla is recognized for its early renderings of humanoid robots and recently updated its associated program, Optimus, showing improved abilities in walking, picking up, and identifying objects. Intel has invested significantly in Figure, an AI robotics company whose general purpose Figure 01 robot is being developed to accomplish tasks including walking up and down stairs, opening doors, and picking up small ob-

jects. Amazon has also entered this domain, having tested Agility Robitic's Digit robot to work in its warehouses; it is capable of high reach, carrying heavier loads, and interacting with humans. Besides these more obvious applications, Shanghai-based Fourier Intelligence is developing its GR-1 humanoid robot to address the increase in demand for health care services precipitated by an aging population. The robot is envisioned as a caregiver, therapy assistant, and companion for the elderly. More contrastingly, scientists at Arizona State University have developed the Advanced Newton Dynamic Instrument robot to study the impact of extreme heat on humans, much like a crash-test dummy is used to measure the impact of car crashes. Whether using humanoid robots in labor situations or for testing extreme conditions, there are both the clear benefits for protecting humans and the perceived risk of reducing available menial jobs.

Soft Robotics/Getting a Grip

Traditionally, robots have not been nimble enough to handle delicate objects: They ap-

ply too much force, making them unsuitable for human replacement. But increasingly, soft robotics have been used for their ability to gently grab and pick up objects, making them ideal for use in warehousing and distribution. Advances in both materials and computer vision are enhancing the efficacy of soft robotics. Researchers at MIT's Computer Science and Artificial Intelligence Laboratory have developed a robotic system called Series Elastic End Effectors, which uses soft bubble grippers and embedded mapping cameras to grasp tools and apply the appropriate amount of force for various tasks. The system is adept enough to write with a pen or wipe up liquid spills. Researchers from the University of California, San Diego developed a 3D printing method that produces soft robotic grippers that only require a bottle of high-pressure gas as their power source, rather than actual robotics, and is a prime candidate for handling delicate materials such as fruits and vegetables. Soft robotics are now also able to account for weight, in addition to delicate touch. Researchers at the Korea Advanced Institute of Science and

Figure's humanoid robots.

Source: Figure
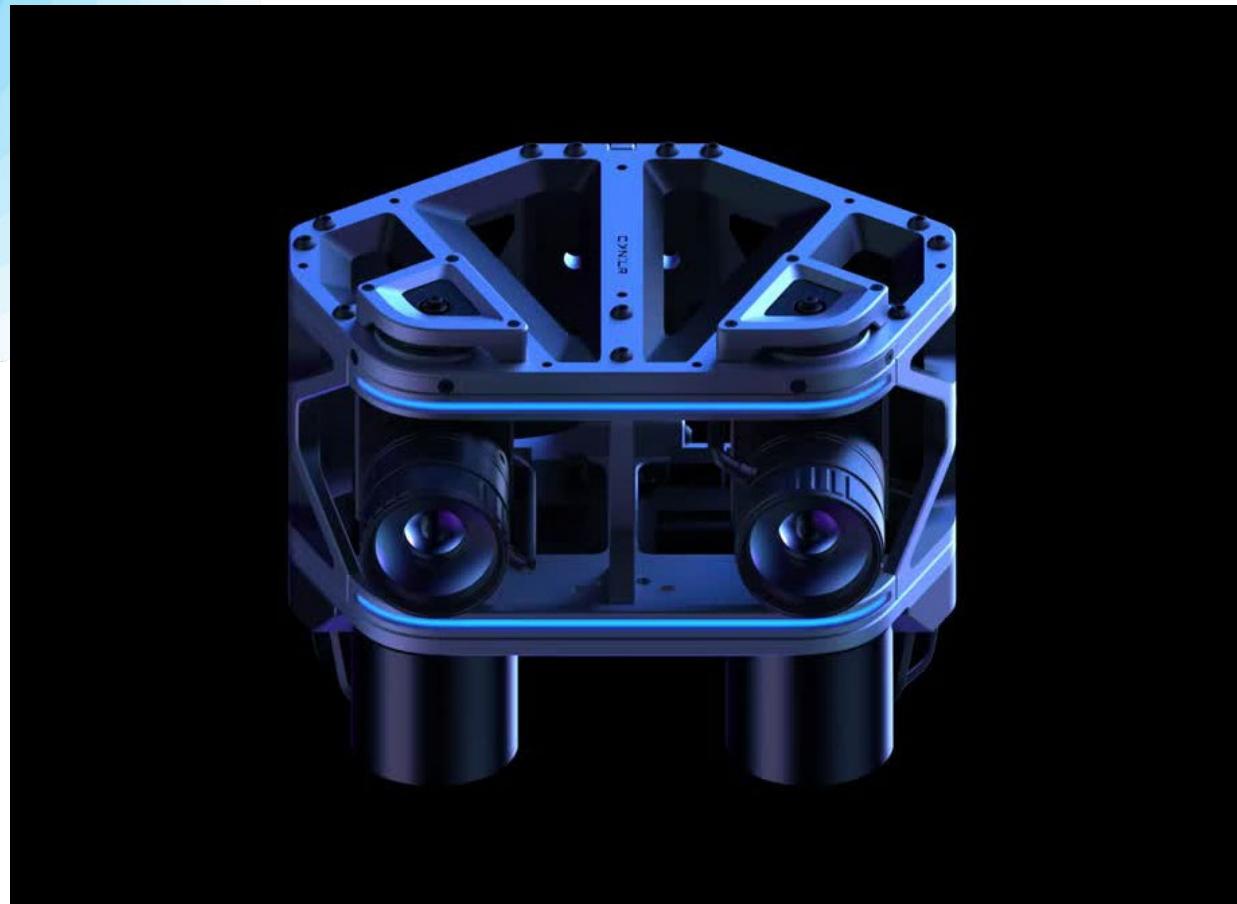
BLURRING THE HUMAN-MACHINE LINE

Technology developed a soft robotic gripper consisting of a woven structure capable of lifting objects weighing more than 100 kilograms. As soft robotics become more dexterous, they will also become stronger.

Robot "Eyes"

As with many advanced technological systems, a constellation of disparate technologies is required to enable the effective and efficient use of the technology. When it comes to robotics, an advanced constellation of tech is required to help the robots "see." While robots are not literally able to see their surroundings, vision, audio, and touch sensor systems, including lidar, radar, 2D and 3D cameras, accelerometers, gyroscopes, bump sensors, force sensors, and temperature sensors, are needed to help robots successfully navigate their surroundings. This phenomenon is also known as sensor fusion. In addition to sensor fusion, other approaches are impacting the way robots sense the world around them. Researchers from the University of Edinburgh have developed a robot navigation system that takes inspiration from ants and helps robots navigate challenging terrains. They created an algorithm that mimics the brain processes ants use during navigation; when it's implemented on hardware that simulates brain computations, the algorithm has outperformed state-of-the-art computer vision systems in navigation tasks. The robotics company CynLr (Cybernetics Laboratory) uses visual cognition and tactile feedback and action to empower bots to "see." CynLr created a visual object intelligence platform that functions with robotic arms to achieve universal object manipulation, which enables the bot to pick up unrecognized objects without needing to recalibrate hardware. Ultimately, these technologies have numerous potential applications for systems requiring navigation, including autonomous cars.

CynLr's CLX1.

Source: CynLr

SCENARIOS

The Evolution of Disaster Response Robotics

When imagining how robotics would impact the world of disaster response, one might have envisioned giant, bulky, transformer-like robots that could be sent to a disaster site and push around debris in their path with brute force. However, this approach could actually make rescue efforts more complicated. Robotics company TechNex Robotics has been fine-tuning its MorphGuard robotics line, which consists of a swarm of tiny, shape-shifting soft-robots measuring 3" x 3" and each weighing around 2 pounds, which employ fluid movements to help those in distress. Taking cues from nature, researchers determined that a swarm or collection of smaller bots could actually be greater than the sum of its parts. While not as comparably strong as their natural counterpart of the ant, these small units can still lift six times their weight, and researchers are diligently working to increase this individual capacity over time. While individually, this may not seem like much, true power comes from the collective unit. When 50 or 100 bots are used in concert, they can deliver meaningful results. But before they are able to lift or transport an individual to safety, they must first locate the victim. By employing fluid and shape-shifting movements, the bots can navigate various terrains and burst through pockets of debris. Smaller, modular bots have proven immeasurably more effective for disaster response than single-unit, bulky robots. From these learnings, researchers are discovering additional applications for this divergent approach.

TAKING CUES FROM NATURE

Quadrupedal Robots

Companies such as Boston Dynamics and Unitree have popularized quadrupedal robots that can be used for a variety of purposes, including security, monitoring, inspection, and data collection. As this type of robot gets more popular, it becomes more agile and used for new applications. Researchers at Carnegie Mellon University's Robotics Institute have used a reaction wheel actuator system to enable quadruped robots to walk on a narrow balance beam, making the bot more versatile and nimble. DEEP Robotics aims to democratize ownership of quadrupedal robots through its Lite3 series, with its most affordable model targeted toward technology enthusiasts and more advanced versions catering to research purposes and opportunities. The Lite3 bot also boasts improvements with the ability to perform horizontal jumps, high jumps, and front flips. Researchers at ETH Zurich have their sights on sending these bots to the moon, having tested their ANYmal robots in simulated lunar activities. Boston Dynamics and Unitree have incorporated GPT-based technologies in their quadrupedal robots, boasting more realistic movements and the perception to understand and interact with users. While Boston Dynamics uses this function to transform its bots into talking tour guides, such signals can begin to fuel our terminator-driven AI doomsday scenarios.

Necrobotics

In 2022, Rice University researchers transformed a deceased spider into a robot, giving rise to a new field called necrobotics. In this process, they manipulated the legs of the spider carcass with a puff of air from a syringe, exploiting the spider's natural hydraulic system for opening and closing its legs. Over the course of the experiment, the spider carcass lifted over 130% of its body weight in more than 1,000 open-close cycles before the joints degraded beyond usability. The results inspired other research teams to further explore the use of insects in robotics. Since the experiment, the Rice University researchers have been recognized for ushering in the era of "necrobotic" design, having been awarded a 2023 Ig Nobel Prize. But reception of this activity has not all been auspicious. Stian Rice and James Tyner at Kent State University published a scathing critique of the practice in the journal Human Geography called "Along came a spider … and capitalism killed it." In it, they bemoan the act of converting death into "useful, productive labor," going so far as to say that the acts "portend a deepening of necrocapitalism and the violence of science." While necrobiotics may lead to the creation of low-cost, eco-friendly substitutes for existing robotic systems, Rice and Tyner raise important ethical concerns as we continue to navigate technological innovation.

Using Live Organisms (Ethically)

Researchers have built applications that use organic and biological compounds and now even specimens themselves for robotic applications. Robotic engineers are increasingly incorporating living tissues into traditional robotics in order to achieve complex behaviors that would be limited by artificial materials. Kit Parker of Harvard's Wyss Institute for Biologically Inspired Engineering, John Dabiri of Caltech, and Janna Nawroth of the Helmholtz Pioneer Campus have collaborated to create a "medusoid," a creature that uses rat muscle tissue attached to a silicone polymer to produce an undulating jellyfish-like robot. Besides using animal tissue in the construction of robots, some researchers are using living organisms in their robot applications. Dr. Josephine Galipon and her team at Japan's Tohoku University have developed a robotic system that uses wood lice and chitons to serve as the effectors or hands of robotic arms. While both examples differ at their foundation in their use of organic matter, they both call into question ethical concerns that arise from this type of technological experimentation. Regardless, they are valuable explorations of how organic material has the potential to improve robotics in ways unachievable through artificial materials.

Insect-Like and Animal-Like Designs

As robots become more capable and sophisticated, engineers are turning to living organisms for inspiration for overcoming even more complex challenges. The US Navy is using

TAKING CUES FROM NATURE
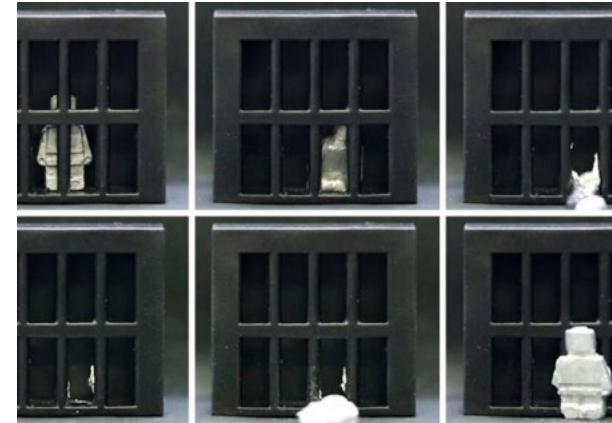
Gecko Robotics' wall climbing and AI-powered bots for building digital models of its vessels to reduce maintenance time and keep vessels out of drydock. ETH Zurich has taken inspiration from geckos but also spiders for its Magnecko, which employs electro-permanent magnet modules on its feet to walk on walls and ceilings, supporting 2.5 times its weight. Caterpillars are the muse for researchers at North Carolina State University, whose robots mimic the movement of the specimen through a system of silver nanowires that use heat to control their movement. Jellyfish have inspired researchers at the Indian Institute of Technology, while researchers at the University of Notre Dame have studied the forms of sea turtles, mimicking the organism's propulsion with front flippers for forward movement and smaller hind flippers for changing direction. And it's not just real animals: Researchers from Tampere University in Finland have taken inspiration from mythical folklore with its fairy-like robots made of stimuli-responsive polymers capable of flight, which could be used to pollinate crops. MIT researchers have developed a platform called SoftZoo that is intended for studying soft robots, making use of 3D models of various animals, such as panda bears, fish, sharks, and caterpillars, to ultimately determine the best configuration for a soft robot's shape. By using nature as a muse, engineers are creating more capable and adaptable artificial creatures.

Fluid Movement

Fluid movement enables robots to work in diverse environments, which holds promise in fields like medicine and machinery repair. Researchers at the Soft Machines Lab at Carnegie Mellon University along with scientists from Sun Yat-sen University and Zhejiang University in China are making breakthroughs in shapeshifting robots that are capable of moving from solid and liquid states through the control of magnetic fields. This phase change allows the robots to accomplish feats such as jumping, climbing, and even escaping from a cage. Researchers envision these robots could be used for tasks including targeted drug delivery, circuit assembly, or the creation of universal screws. To capitalize on this modality in another unique way, researchers at Northwestern University have created a soft quadruped robot that could be used in hazardous situations: it can sense damage and autonomously repair itself before resuming movement. The robot, which is shaped like the letter X and powered by compressed air, has a layer of self-healing sensors on its top surface. The sensors are made of transparent rubbery material, and if one is cut, it can chemically react to fuse back together. Researchers at the University of California, Santa Barbara have developed a vine-like robot that can detect and move toward heat sources. The robot is also capable of moving around simple obstacles and bending backward to ward off heat and could be used for search-and-rescue and firefighting missions.

Miniature metal shapeshifting robot liquefies itself and reforms to escape a cage.

Source: Carnegie Mellon University

TAKING CUES FROM NATURE

Moving Across Modalities

Robotics are no longer limited to a single modality or simple movements. They are becoming more complex in their operation and maneuverability, capable of driving, jumping, crawling, and even mimicking origami. Caltech is working on a versatile robot called the Multi-Modal Mobility Morphobot that can switch between various modes, including four-wheeled movement, crouching, climbing steep slopes, standing upright with propellers, and turning into a flying quadcopter. Such characteristics make it a prime candidate to assist in search-and-rescue missions, as it is able to cover very diverse terrains. Researchers at MIT have created tiny soft-bodied robots that can be controlled by a simple magnetic field, enabling them to walk, crawl, and swim and making them ideal for tasks in confined spaces and suitable for transporting delicate cargo. Researchers at the University of Washington have created small robotic devices known as microfliers. These devices can change how they descend by folding themselves, using an origami technique called Miura-ori. OrigaMechs, developed by researchers at the University of California, Los Angeles add data processing capacity to the concept of origami robots. The researchers have embedded flexible and electrically conductive materials into a precut, thin polyester film sheet, resulting in fully flexible robots that can perform various complex tasks without reliance on semiconductors. As robots begin to function in multiple modalities, they become better suited for extreme environments and are imbued with new abilities for sensing, deciding, and responding.

University of Washington's microflier.

Source: Mark Stone/University of Washington

SCENARIOS

Self-Regulating and Repairable Robots

QuantumSync Robotics has emerged as a trailblazer in the field, redefining the traditional boundaries in both business and manufacturing landscapes. It's enabled a world where robots not only perform tasks efficiently but also possess the capability to diagnose and fix issues autonomously, leading to a new era of self-healing machines. By applying the Robotics-as-a-Service (RaaS) business model, QuantumSync can offer customers a full suite of robotics applications from the ground up, or supplemental robotics that just perform the diagnostic and repair functions for a preexisting robotics system.

Robots equipped with QuantumSync's central nervous system, known as AdaptiveMind, become highly self-aware of themselves and the robots integrated into their ecosystem. As a robot carries out its designated tasks, such as a manufacturing component or warehousing task, sensors and advanced diagnostics constantly evaluate its condition. When a robot detects a deviation from optimal functioning or predicts an impending failure, it notifies the network of a self-repair protocol. The system calculates the severity of the maintenance or repair and assigns a nearby robot with the task of resolving the issue, whether this be a simple calibration or something more involved such as printing and extruding replacement parts. While this will affect overall performance in the moment, such an approach reaps meaningful returns in the long run. Capable operations will be able to continue in real time while addressing pressing issues with urgency and prioritization. By applying new business models with novel robotics, QuantumSync Robotics continues to revolutionize a more fully automated manufacturing future.

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Nick Bartlett is a Director at the Future Today Institute and leads our Insurance practice area.

Before FTI, he held positions in corporate strategy and insights generation roles, serving as a partner to senior leadership at multiple Fortune 100 financial services companies. Throughout his career, he has specialized in framework design, corporate innovation, strategic management, and insurance.

Nick has an extensive background in developing strategic insights across a variety of industries (e.g., manufacturing, transportation, construction, energy) and subject matter areas (e.g., small business, mobility, robotics, platforms & ecosystems), in addition to the shifting nature of business and consumer preferences. He has deep experience developing and implementing trend modeling and signal iden-tification for large organizations. Nick has also led the design and establishment of internal foresight and scenario development capabilities across multiple institutions.

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COMPUTING

Future Today Institute

TABLE OF CONTENTS

TOP HEADLINES

AI's demand for computational power challenges computing paradigms, driving researchers to rethink architectures and governments to rethink semiconductor policies.

01 Computing industry moves in-house

As geopolitical tensions and supply chain concerns rise, there has been a push toward on-shoring critical technologies, such as semiconductors and 6G-enabling technologies. The US and its allied nations have imposed export restrictions on semiconductors and related equipment to China.

02 AI workloads demand new architectures

The commercialization of AI requires novel architectures to manage its demanding workloads, spurring research into computer architecture design. Companies are looking to alternative energy sources like nuclear and geothermal to power data centers.

03 Organoid Intelligence Represents A New Computing Frontier

Organoid intelligence harnesses stem cell-derived brain organoids to explore learning, memory, and cognition, potentially creating a biological computer.

04 New techniques emerge for error-prone quantum computers

Quantum researchers are focused on tackling the noise and error issues inherent to quantum computing.

05 AI-centric form factors emerge for personal computing

As AI transforms how we engage with computers, businesses are exploring new interfaces and user experiences, focusing on AI-driven interactions. This includes voice-controlled wearables and portable devices with chatbots as their core, making AI more central to our interactions.

STATE OF PLAY

AI is enabling novel form factors for more natural human-computer interaction, while its intensive workloads challenge existing computing models. These developments, combined with the risks of advanced AI in adversarial hands and supply chain vulnerabilities, are leading the US and allies to reevaluate their trade relationships.

Driven by artificial intelligence, humans and computers are in a virtuous cycle: a self-reinforcing loop where advancements in one area lead to progress in the other, and vice versa. In this case, humans created computers, which improve human productivity. More advanced humans created more advanced computers and so on. As the virtuous circle goes round and round, the separate entities—humans and computers—will get closer and closer to one another.

AI's voracious computational appetite is prompting companies and researchers to rethink conventional computing architectures. The Von Neumann architecture, which propelled the silicon era to this point, is now insufficient for meeting AI's computational demands. To unlock the full potential of AI in an energy-efficient, cost-effective way, researchers are experimenting with alternative computing architectures, and they are finding inspiration by looking inward—to the human brain itself. As the most efficient computing system known, the brain's architecture is ideally suited for AI workloads.

So, researchers came up with neuromorphic computing, computer architectures inspired by the biological brain's structure and function. Just like our brains, neuromorphic computers can simultaneously store and process information, a capability that makes them more energy efficient than classical computers. Researchers at Johns Hopkins University are taking this even further. Last year they broke ground on a new computing field called organoid intelligence. Whereas neuromorphic computing aims to mirror the brain's efficiency in the design of computing systems using silicon, organoid intelligence aims to utilize the inherent capabilities of biological materials or systems for information processing. Basically, organoid intelligence uses human brain cells as a computer.

This isn't merely a matter of drawing inspiration from the brain; it's an endeavor to adapt and enhance our innate physiological blueprint to fabricate computational devices that not only match the efficiency of the human brain but surpass it in intelligence. Simultaneously, breakthrough technologies like soft implantable brain-computer interfaces are

STATE OF PLAY

facilitating the tangible integration of our biological essence into computational systems. The future of computing, it seems, is not an external tool that we engage with but rather, the future of computing is an innate element fused into our sensory perception, motor control, and cognitive processing. This vision posits a future where computing is no longer an external interaction but an integrated aspect of our very being.

To get to a future where computing seamlessly merges with the human experience, it's crucial to recognize that this technological progression won't occur in a vacuum. It is intertwined with, and frequently stimulated by, a complex mosaic of geopolitical events and international frictions. This can be observed in the mounting tensions, chiefly between the US and China, over powerful chips. The US and its allies are implementing restrictions on the export of advanced semiconductors and their manufacturing equipment to China. The effectiveness of these restrictions, however, is challenging to ensure. China has already bypassed these export controls and obtained sophisticated Nvidia chips. Additionally, technologies like RISC-V, freely downloadable from the internet, will likely become pivotal for Chinese companies and government entities aiming to rival US expertise in semiconductor design.

There is also a battle between the US and China over the pursuit of quantum supremacy. The first nation to achieve this could place the other in a precarious position from a national security standpoint. The sense of urgency is further amplified by an increasingly protectionist global outlook, catalyzed by the vulnerabilities in worldwide supply chains exposed by the COVID-19 pandemic. Consequently, governments worldwide are taking measures to repatriate the production of vital technologies, a movement that includes quantum technologies, semiconductors, and even the emerging realm of 6G telecommunications. This intricate nexus of innovation and geopolitics is a testament to our age—a time of immense change and potential, when computing not only drives our technologies but also shapes the very contours of our societal and global narratives.

KEY EVENTS

FEBRUARY 28, 2023

OI: A new scientific field

Scientists form a new field, organoid intelligence (OI), considered the frontier of biocomputing.

MAY 22, 2023

Long-distance quantum internet

Researchers achieve the first long-distance quantum repeater node for telecommunications, transmitting quantum information over 50 km.

NOVEMBER 6, 2023

US Further Restricts Chip Exports

The measures aim to tighten China's access to US semiconductor technology, a key element in developing powerful AI platforms.

MARCH 21, 2023

GPU-accelerated quantum device

Nvidia announces the world's first GPU-accelerated quantum computing system.

JUNE 14, 2023

Closer to quantum advantage

UC Berkeley/IBM paper demonstrates a path toward quantum advantage over classical computers.

LIKELY NEAR TERM DEVELOPMENTS

AI, ARCHITECTURE & ALLEGIANCE

Geopolitical tensions are accelerating some key computing developments. Expect semiconductor talent shortages as nations adjust how they manage skills for self-reliance. Also expect the rush to prepare for "Q-Day" to become more urgent as countries race toward quantum advantage. We will see more companies boast quantum-resistant cryptography as a value proposition. And as countries become more wary of supply chain disruptions, more inputs will be brought in-house. As nations do this, RISC-V adoption may increase.

Technological developments in AI are also driving near term developments. To power AI, companies are rethinking computing architectures using inspiration from the human brain and existing gaming devices. AI will soon flip the script on human-computer interaction; rather than users learning to operate computers, AI allows computers to learn to interact on human terms. With AI, the computer will adapt to the person—not the other way around.

Research and Debates on OI

Expect a surge in organoid intelligence research. Organoids may be the key to AI's efficient boost, but the convergence of AI and OI may stir ethical debates.

Chip Freedom

Expect a rise in RISC-V adopters as it transforms the chip industry. Offering freedom from costly licenses, RISC-V enables custom, application-driven hardware, making chip design more accessible, thereby lowering the entry barrier.

Surge in Q-Day Preppers

Businesses will prepare more seriously for "Q-Day"—when quantum computers can break internet encryption protocols. As China and the US both achieve breakthroughs toward quantum advantage, expect a surge in investments in this domain.

Semiconductor Skills Shortage

Anticipate a talent crunch in the semiconductor sector as countries aim to internalize production. This skill gap will necessitate refocusing, driving universities and communities to prioritize these skills.

The New BYOD Policy: Gaming Devices

AI requirements will spur non-gamers toward powerful gaming devices, prompting demand for enterprise software integration. This signals a new wave of bring-your-own-device hardware—powerful yet portable. Expect increased enterprise application integration with such devices.

AI-Driven Form Factors

Expect an emergence of new form factors driven by AI, that diverge from the conventional laptop, keyboard, and mouse setup, as AI facilitates more intuitive communication methods. We might also see a surge in specialized devices designed for specific AI applications, like dedicated translation gadgets or AI-enhanced cameras.

11 MACRO SOURCES OF DISRUPTION

| Technology | Media & Telecom | Demographics | Environment | Government | Public Health | Education | Geopolitics | Infrastructure | Economy | Wealth Distribution |

WHY COMPUTING TRENDS MATTER TO YOUR ORGANIZATION

Chip Talent Shortage

Semiconductor companies may face growth constraints due to a scarcity of skilled workers, which could slow innovation or production delays. These difficulties can ripple through to other industries, such as automotive, which heavily rely on semiconductors. Amid rising geopolitical tensions, companies that secure talent may gain a competitive edge.

Achieving Independence With RISC-V

RISC-V's open-source nature empowers companies to customize chip designs, catering to specific needs. Its free-to-use model makes it attractive for budget-conscious companies. This lessens dependence on particular vendors, mitigating supply chain risks and bolstering resilience. Particularly in China, RISC-V advances national objectives of curtailing foreign IP reliance and achieving semiconductor self-sufficiency.

Using AI to Design Chips for AI

AI-designed chips may increase product performance and reduce costs, shifting competitive dynamics and market shares. For talent, expect less demand for chip designers and more for AI specialists. The AI optimization of chip design could disrupt semiconductor market leadership, with innovators gaining the upper hand. Further, cost-effective chip design may spur innovation in AI-dependent sectors, leading to new business opportunities.

Portable PCs: From Gaming to the Enterprise

The portable PC market, initially fueled by gamers, shows promise for enterprise users as a lightweight, powerful secondary device. Portable PCs could soon be viewed as a BYOD option for enterprises, disrupting reliance on laptops. If optimized for business, portable PCs may find a role as compact work devices, expanding hardware and software markets.

Investment in Quantum-Resistant Cryptography
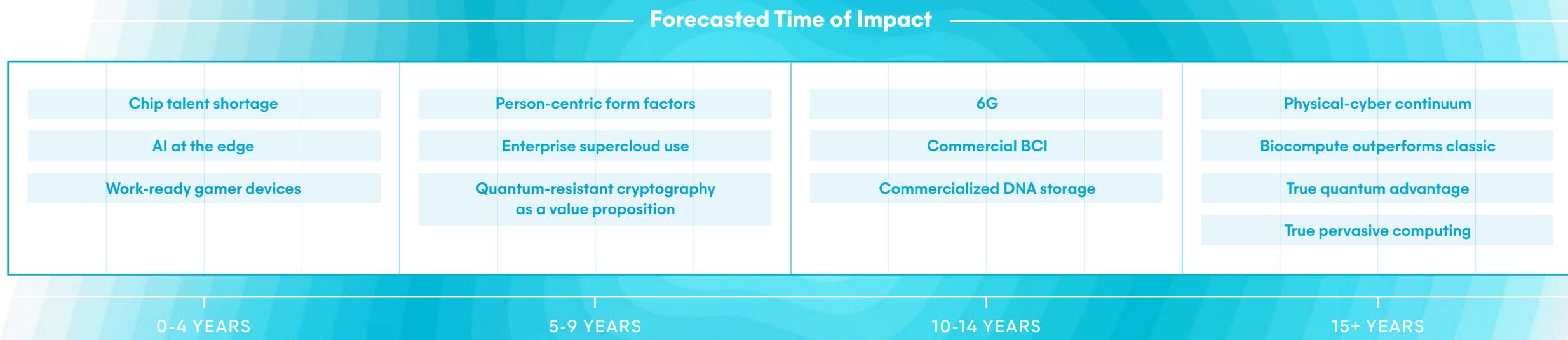
Quantum superiority poses an existential threat to business data. The first to achieve quantum advantage will be able to upend security by quickly cracking encryption or by unmasking anonymized data. Mitigating this risk will require a complete transition to quantum-safe cryptographic algorithms. Though the security challenges are daunting, solutions are emerging to fortify for the quantum era.

Unintended Consequences of Export Controls

As the US tightens restrictions on semiconductor exports, the potential for Chinese retaliation poses a threat to the global consumer electronics market. China's dominance in legacy chip production, critical for a wide range of products, from household appliances to military hardware, means these restrictions could lead to higher prices and scarcity of various consumer electronics globally.

WHEN WILL COMPUTING DISRUPT YOUR ORGANIZATION?

Forecasted Time of Impact

0-4 YEARS	5-9 YEARS	10-14 YEARS	15+ YEARS
Chip talent shortage	Person-centric form factors	6G	Physical-cyber continuum
AI at the edge	Enterprise supercloud use	Commercial BCI	Biocompute outperforms classic
Work-ready gamer devices	Quantum-resistant cryptography as a value proposition	Commercialized DNA storage	True quantum advantage
			True pervasive computing

OPPORTUNITIES & THREATS

Threats

Ethical debates about organoid intelligence's human-like cognition may impede research, delaying innovations in health care, computing, and robotics.

Reshoring semiconductor manufacturing to the United States can involve significantly higher costs compared to overseas production, requiring government subsidies and policy reforms to offset higher domestic labor and tax expenses if the U.S. aims to make domestic chip fabrication globally competitive.

With notable talent shortages in semiconductors, onshoring success requires workforce development, immigration reform, and public-private partnerships for training.

Integrating neuromorphic systems with existing computer architectures poses complex challenges for synchronizing biological cognition with digital logic requiring new design paradigms.

Organoid and neuromorphic technologies risk ethical and legal scrutiny over human-like synthetic intelligence; clear governance is needed to enable innovation responsibly.

Quantum advantage may enable cracking encryption, threatening security; global rules and norms are needed to prevent misuse while fostering continued progress.

Increasing US-China tension over quantum risks could stifle collaboration; a technology embargo could cede leadership. Cooperative policy is key to preventing a tech cold war.

Opportunities

RISC-V's open architecture democratizes chip design, empowering innovation and strategic autonomy for companies and nations, reducing reliance on external suppliers.

Applying AI to optimize chip design unlocks major performance and cost efficiencies, enabling next-gen semiconductors accessible to more applications.

Neuromorphic computing's efficiency from processing and storing data simultaneously is a breakthrough for energy optimization vital for sustainability across industries.

Neuromorphic chips' brain-like adaptability can revolutionize machine learning, making algorithms more robust and powerful for transformative AI applications.

Quantum internet provides virtually unhackable communications, realizing enhanced data/infrastructure security to protect information at unprecedented levels.

Quantum-as-a-service opens quantum's potential to more industries and researchers, fostering innovation and progress toward real-world impact.

More efficient AI edge models expand access for new applications and users, driving innovation and economic opportunity by democratizing transformative technology.

INVESTMENTS AND ACTIONS TO CONSIDER

1

As AI permeates enterprise apps, modify software and operating systems to support mobile form factors like gaming PCs, which already offer advanced portability and processing that mobile workers will expect. Enable apps on compact yet powerful devices, and support policies like BYOD as gaming converges with productivity needs.

2

For enterprises using hybrid and multicloud, consider implementing the supercloud to save developers time managing complex multicloud environments. Supercloud abstraction layers integrate disparate clouds into one platform, handling management overhead so developers can focus on revenue-generating activities.

3

Prepare for 6G by investing now in the foundational technologies that will enable the immersive experiences promised by a 6G-enabled cyber-physical continuum. For instance, consider investing in technologies like terahertz communications, advanced edge computing, integrated satellite networks, and advanced materials.

4

Create domestic internship and apprenticeship programs to build talent pipelines in semiconductor and quantum skills, where shortages loom due to onshoring. Partner with schools to develop a homegrown workforce proficient in these technologies vital for national strategic interests.

5

Diversify sourcing of critical components to reduce overreliance and risk from any single country or region, and improve resilience. Build relationships with multiple suppliers and partners to mitigate concentration and gain flexibility to adapt to changing political and market conditions.

6

Fund research on organoid intelligence and neuromorphic computing, enabling collaborations to translate findings into commercial technologies. Partner with academia and startups on initiatives like brain-inspired chips and synthetic neural tissues to drive innovation in human-like cognition for applications from health care to robotics.

CENTRAL THEMES

AI-Driven Design

As AI's computational demands grow, traditional architectures are falling short, paving the way for alternatives like photonic and neuromorphic computing. Photonic computing leverages light's speed for faster and energy-efficient computations, providing a parallelism suitable for AI's requirements. Neuromorphic computing, mimicking the brain's structure, merges memory and processing, drastically reducing data fetch times for AI tasks. We aren't just reevaluating the architectures themselves—we are reevaluating how we even think about the architecture. And it may be the case that we aren't the best candidates for the job. The best candidate for designing an architecture suited to AI just might be AI. It's aiding in optimizing transistor placement, addressing cost, speed, and power efficiency issues. AI's impact is thus two-fold; it's driving the demand for advanced computation and also contributing to its design.

Protectionist Policies, Attitudes

The 2022 Chips Act provides roughly $280 billion to boost domestic research and manufacturing of semiconductors in the US, aiming to make the country less vulnerable to disruptions in the supply chain by bringing semiconductor fabrication plants in-house. We're now seeing similar protectionist attitudes emerge in other strategic technology areas like quantum computing and the technology that will eventually enable 6G. However, despite subsidies, this shift may still increase US production costs compared to countries like Taiwan, pressuring chip producers. It could also trigger talent shortages in relevant skills. While the goal is technological independence, these protectionist strategies may have implications on cost, talent acquisition, and global cooperation in key tech sectors. Pursuing self-reliance has trade-offs.

Computing Gets More Personal

Computers are becoming deeply integrated with us, redefining the "personal" in personal computing. Devices such as MIT Media Lab's AttentivU glasses enable us to control robots like Boston Dynamics' Spot with our eyes, while spray-on meshes developed by Seoul National University and Stanford University enable AI to interpret our hand gestures. Everyday objects are transforming into interactive interfaces, and as tech advances, our devices comprehend us more intimately. We're becoming interfaces for devices, which are morphing into extensions of us. Screens are moving closer to our faces via glasses and AR/VR headsets, while our brains can control artificial limbs, exemplifying this profound integration. Even our own skin can be an interactive interface, as seen with Cornell University's SkinPaper, which facilitates on-skin interactions for a range of applications, from art to health care.

CENTRAL THEMES

Accelerating Growth Through Open Source

Open-source software is spreading into new domains previously dominated by proprietary solutions. One example is in quantum computing, where the high costs of proprietary hardware and software has made quantum experimentation inaccessible for most researchers. Open-source quantum software toolkits like Qiskit and SuperConga are changing this by providing free access to simulate quantum circuits and materials. This allows a broader community to collaborate and drive innovation in quantum computing. Similarly, open-source chip architectures like RISC-V are transforming the semiconductor industry. Traditionally, companies like Intel and Arm have controlled chip design and manufacturing, but RISC-V makes instruction set architectures freely available for anyone to build custom chips. By opening access, open source allows more minds to tackle complex problems together, leading to advancements in fields that were previously dominated by closed, proprietary systems.

Abstraction: Layers on Layers

As computing grows more complex, new abstraction layers emerge to simplify access. In quantum computing, companies like Horizon Quantum Computing compile classical code so developers can program without grasping quantum mechanics. Quantum-as-a-service similarly insulates users from hardware intricacies. Conventional computing exhibits similar abstraction layers upon layers. Early cloud computing abstracted physical servers, enabling users to focus on applications without infrastructure concerns. Now "supercloud" layers integrate disparate cloud platforms, further simplifying management and cross-ecosystem operations. These abstraction layers divorce users from technical complexities, dramatically streamlining processes. Developers avoid wrestling with infrastructure intricacies, innovating instead at higher levels. Users interact with user-friendly interfaces rather than deal with technical details.

Researchers Take on Noise

Quantum computers face significant reliability challenges due to noise and errors that introduce inaccuracies during computations. "Quantum noise" refers to the inherent fluctuations and uncertainties that arise in quantum systems due to the principles of quantum mechanics. Researchers are pursuing various strategies to mitigate these issues. Noise reduction techniques aim to isolate qubits from environmental disturbances that cause errors. Other approaches focus on modeling the impact of noise to estimate and subtract out its effects after computations finish. There are also efforts to optimize qubit connectivity to reduce noise. Progress is happening, but substantially reducing errors remains an ongoing challenge. The inherently probabilistic nature of quantum physics means some baseline of noise will likely persist. However, researchers are encouraged by experimental demonstrations showing meaningful computations are possible even on today's error-prone hardware. Continued incremental advances in mitigating noise will help make quantum computers more robust and capable. Despite remaining limitations, researchers in this field are optimistic about eventually achieving practical applications.

ONES TO WATCH

Alireza Marandi, assistant professor of electrical engineering and applied physics at California Institute of Technology, for research on photonic cellular automata.

Alon Loeffler, synthetic biological intelligence postdoctoral scientist at the University of Sydney, for demonstrating nanowire networks can exhibit both short- and long-term memory like the human brain.

Ben Lanyon, physicist in the Department of Experimental Physics at the University of Innsbruck, for his work on the first long-distance quantum repeater node for telecommunication networks.

Brian Johnson, postdoctoral researcher at University of Colorado Boulder, for developing new soft actuators, sensors, and control algorithms for intelligent robotic materials.

Christina Tringides, postdoctoral fellow at ETH Zürich, for research on hydrogel scaffolds for neural cell differentiation.

Cindy Hsin-Liu Kao, assistant professor and director of the Hybrid Body Lab at Cornell, for work on wearable and ubiquitous computing, particularly on-skin interfaces.

Dirk Grundler, head of the Lab of Nanoscale Magnetic Materials and Magnonics in the School of Engineering at the Swiss Federal Institute of Technology, Lausanne, for research on magnon-based computation.

Brad Aimone, a Distinguished Member of Technical Staff in the Center for Computing Research at Sandia National Laboratories, for research on neuromorphic computing.

Chueh Loo Poh, principal investigator and professor at the College of Design and Engineering at the National University of Singapore, and the NUS Synthetic Biology for Clinical and Technological Innovation, for work on developing a biological camera that captures and stores images directly into DNA.

Hussam Amrouch, professor of AI processor design at the Technical University of Munich, for work on energy-saving AI chips.

Sanghyo Lee, senior research associate at University of Cambridge, for work on development of next-generation smart textiles.

Gordon H.Y. Li, graduate student at California Institute of Technology, for research on photonic cellular automata.

Jonathan Xu, researcher at Stanford and the National University of Singapore, for his work on brain image reconstruction using fMRI.

Mikael Fogelström, professor of theoretical physics at Chalmers, for his work on SuperConga, an open-source framework for mesoscopic superconductivity.

Nataliya Kos'myna, research scientist at MIT, for work on brain computer interface systems and research on fluid interfaces.

Pat Pataranutaporn, research assistant at MIT, for his research on synthetic virtual humans and synthetic biology, specifically at the interface between biological and digital systems.

Patric Holmvall, postdoctoral researcher in condensed matter physics at Uppsala University, for work on developing open-source, freely available software to speed quantum research.

Sajant Anand, Ph.D. candidate at University of California, Berkeley, for research on tensor network algorithms for simulation of quantum many-body systems on both classical and quantum computing.

Sunil Pai, quantum architect at PsiQuantum, for research that demonstrates in situ back-propagation can train photonic neural networks to solve a task.

Thomas Hartung, professor at Johns Hopkins, for his work to develop a collaborative, multi-disciplinary program that aims to establish organoid intelligence as a genuine form of biological computing.

Vasha DuTell, postdoctoral fellow at MIT, for her work on perceptual straightness in computer vision.

Yasha Iravantchi, doctoral candidate at University of Michigan EECS, for work on developing novel sensing hardware, particularly SAWSense.

Youngseok Kim and **Andrew Eddins,** research scientists with IBM Quantum, for their 2023 paper "Evidence for the Use of Quantum Computing Before Fault Tolerance."

Bradley Theilman, a postdoctoral appointee at Sandia National Laboratories, for research on neuromorphic computing.

IMPORTANT TERMS

Biocomputer
A computer that uses biological molecules like DNA and cells to store and process information.

Brain-computer interface (BCI)
A direct interface between the brain and computer that can enable control and communication by thought alone, with potential to help people with disabilities as well as elucidate cognition.

Cellular automata
Computational models that evolve in discrete space and time according to simple rules based on local neighbor interactions.

Central processing unit (CPU)
The key computer component that performs the computations, makes decisions on data, and tells the other components what to do. You can think of it as the computer's mission control center.

Classical computer
The standard binary digital computer that manipulates zeros and ones to store data and perform computations sequentially using hardware chips and switches.

Exascale computers
Supercomputers capable of performing over 1 exaFLOPS, which is a quintillion calculations per second.

Fault tolerance
The ability of a quantum system to operate reliably despite errors and noise.

Form factor
The overall physical attributes and dimensions of a device according to standard specifications or for particular use cases. It impacts the usability and compatibility of hardware.

Graphics processing unit (GPU)
A specialized circuit designed to rapidly process and manipulate computer graphics and image data.

Hybrid classical-quantum
A computational architecture that combines both classical computers and quantum computers to exploit the complementary strengths of each.

Machine learning
A subfield of artificial intelligence that trains algorithms to learn from data, identify patterns, and make predictions or decisions without being explicitly programmed.

Magnonics
Aims to develop devices and circuits that use magnons for information processing and transmission.

Moore's law
The observation made by Intel co-founder Gordon Moore in 1965 that the number of transistors on an integrated circuit doubles about every two years. Recent challenges suggest Moore's law is approaching fundamental limits due to physics and cost.

Nanowire networks
Meshes or arrays of nanoscale wires used to build devices and circuits. They can exhibit unique optical, electrical, thermal, and chemical characteristics.

Neuromorphic computing
Computer architectures that are inspired by the biological brain's structure and function.

Open source
Computer software or other products with source code that anyone can inspect, modify, and enhance.

Organoid intelligence
A new scientific field of study that aims to actualize biological computing by utilizing 3D cultures of human brain cells and brain-machine interfaces.

Parallel spatial computing
Computer architectures optimized to perform many operations simultaneously across a large grid or array of simple spatial processing elements.

Perceptual straightness
The ability to perceive dynamic visual information and transform it into a stable mental representation.

Pervasive (ubiquitous) computing
Aims to seamlessly integrate computer hardware and software into all objects and activities, creating an always available, helpful computing environment.

Photonic chips
Integrated circuits that generate, manipulate, and detect light waves and photons to process information.

Q-Day
The hypothetical point in the future when a fully operational quantum computer capable of running practical quantum algorithms finally becomes available.

Quantum advantage
Also known as quantum supremacy, refers to the potential capability of quantum computers to solve

IMPORTANT TERMS

certain problems that are intractable for classical computers in practical timeframes.

Quantum-as-a-service
The provision of quantum computing resources on demand as a cloud service.

Quantum circuit model
The most common model for quantum programming and computation. One key aspect is that programs are expressed as circuits consisting of qubits and quantum gates operating on the qubits. The circuit model provides a simple abstraction to reason about quantum programs.

Quantum computer
A type of computer that utilizes quantum mechanical phenomena like superposition and entanglement to perform computations. Unlike classical computers which operate on binary bits (0 or 1), quantum bits, or qubits, these computers can represent a 0, 1, or a quantum superposition of both states at the same time. Since they consider multiple possibilities simultaneously, they can potentially be vastly faster at some types of problems than classical computers.

Quantum entanglement
A phenomenon in which two or more quantum particles are intrinsically linked to each other in such a way that the state of one particle cannot be described independently of the others, even when separated by a large distance.

Quantum internet
A hypothetical global quantum communication network that connects quantum processors using quantum entanglement and teleportation.

Quantum superposition
Allowing a quantum system to exist in multiple possible states at the same time until it is measured. The quantum parallel processing enabled by superposition is fundamental to achieving speedups and novel applications using quantum computers.

Qubit
The basic unit of information in quantum computing. Unlike classical bits, qubits can be in a superposition of 0 and 1 simultaneously. The superposition, entanglement, and interference properties of qubits are what allow quantum algorithms to efficiently solve certain problems that are believed to be intractable on classical computers.

RISC-V
An open-source instruction set architecture based on established reduced instruction set computer (RISC) principles.

RSA encryption
A public-key algorithm currently widely used for secure data transmission that will become insecure in the quantum era. RSA security depends on the difficulty of factoring large integers, which quantum computers will be able to efficiently solve.

Superconductor
A material that can conduct electricity with zero electrical resistance. This means that, unlike typical conductors, superconductors can carry an electrical current indefinitely without losing any energy to heat or electrical resistance.

CHIPS

CHIPS

Chip Onshoring

The CHIPS Act, signed into law in August 2022, has sparked numerous initiatives to bolster the US semiconductor industry. Over 50 new chip facility projects have been announced since the legislation was introduced, with private companies pledging over $210 billion in investments. Intel unveiled plans for a $20 billion chip fabrication complex outside Columbus, Ohio; Micron plans to invest up to $100 billion over the next 20-plus years; Samsung is exploring building 11 plants in Texas with one plant already costing the chipmaker $25 billion ($8 billion more than forecasted). General Motors announced an unprecedented, long-term partnership with GlobalFoundries, which will establish dedicated chip production capacity exclusively for GM in upstate New York. Taiwan Semiconductor Manufacturing Co. (TSMC), the world's largest advanced chip manufacturer, broke ground on a major facility in Phoenix and increased its investment to $40 billion. The aim of the onshoring efforts is to reduce US vulnerability to foreign disruptions. However, the US is making a trade-off with this approach; onshoring is often costlier. In a recent submission to the US Commerce Department, TSMC complained the Phoenix plant would cost substantially more than an equivalent facility in Taiwan, citing higher wages and taxes, lower productivity, a greater likelihood of delays, and more stringent regulations.

These onshoring initiatives coincide with a tightening of tech export controls to China. In March 2023, NVIDIA introduced the H800 chip, compliant with Commerce Department guidelines and a substitute for the restricted H100 chips in China. October 2023 saw new restrictions halting China-specific A800 and H800 exports, disrupting NVIDIA's plans to fulfill additional orders. This shift forced China to turn to non-US chip suppliers, resulting in companies like Baidu, a long-term NVIDIA client, opting for Huawei's AI chips instead.

Chip Talent Shortage

The global semiconductor industry is grappling with a shortage of skilled talent. According to some estimates, the US will face a deficit of 70,000 to 90,000 workers over the next few years, ballooning to a shortfall of 300,000 engineers and 90,000 technicians by 2030. Due to a shortage of skilled labor, TSMC has reported new delays in the progress of its $40 billion Arizona facility. The skills gap extends beyond America's borders. Taiwan, a leader in cutting-edge chipmaking, faced a shortage of over 30,000 workers at the end of 2021, up 77% from 2020. China's massive semiconductor industry is wrestling with a shortfall of 300,000 skilled workers. South Korea expects at least 30,000 fewer skilled workers than required over the next decade as universities produce less than half the number of graduates needed. In Japan, major manufacturers warn that the industry's revival is in jeopardy without 35,000 additional engineers. European semiconductor growth is also hampered by a substantial talent deficit, industry leaders say. The push to reshore semiconductor manufacturing has put the unintended consequences into sharp focus. While bringing chip production back to America could bolster supply chain security, developing talent will take time.

The booming US semiconductor sector faces a shortage of skilled chip fabrication skills, raising concerns that a lack of qualified talent could jeopardize billions invested in expanding domestic chip manufacturing.

CHIPS

Chips to Optimize AI Workload

Embedding advanced AI comes at a computational cost. For instance, researchers estimated that for Google to add GPT-3 into every search query, it would need 2.7 billion of NVIDIA's old A100 chips, which would cost more than $40 billion. This staggering price tag highlights the demand for more efficient AI chips to make AI scalable and accessible. NVIDIA responded with the H100 chip, optimized for generative AI and named after pioneer Grace Hopper. With substantially faster processing than previous chips, the H100 is crucial for companies seeking to develop AI services. In November 2023, NVIDIA escalated its AI computing power further with the NVIDIA HGXTM H200, building on the HopperTM architecture. As the first GPU with HBM3e memory, the H200 enables faster processing essential for generative AI and large language models, while boosting scientific computing. Compared to the A100, it delivers double the memory capacity and 2.4 times more bandwidth. In a parallel development, Amazon Web Services (AWS) announced Trainium2, engineered specifically for training AI models. Moreover, AWS plans to provide access to NVIDIA's next-generation H200 GPUs through a specialized computing cluster, accessible to both AWS customers and NVIDIA. To reduce dependence on Nvidia, Microsoft has developed its proprietary AI chip designed for training LLMs. Additionally, the company has created its own ARM-based CPU tailored for cloud workloads. These chips will be used to power Azure data centers for their AI-hungry customers.

Researchers are also advancing AI chip architecture in ways that could shape the next generation. For example, one computer scientist developed an in-memory computing chip that processes and stores data directly within each transistor, taking inspiration from the human brain's ability to simultaneously process signals and store information. This chip delivers twice the power efficiency of alternatives.

Photonic Chips

With the continued growth of AI models, energy consumption also escalates. This is where photonic AI chips, which operate using light rather than electricity, show promise in improving efficiency. They are more energy efficient than alternatives because they excel at performing matrix multiplications, a fundamental operation in deep learning models. But until now, the application of photonic AI chips was limited to inference tasks, as they struggled with implementing the vital algorithm required to train neural networks, known as backpropagation.

A team at Stanford has overcome this challenge by successfully training AI on an optical chip, a first in the field. Their photonic chip allows light signals to pass in both directions through an optical neural network, and it has built-in light detectors to measure the intensity of light passing through each component. This enables the chip to optically implement backpropagation. As a result, the researchers were able to train a simple neural network to label data points with up to 98% accuracy. While there is still room for improvement, this milestone demonstrates the potential of photonic processors to increase the energy efficiency of AI.

RISC-V

RISC-V, an open-source computer chip architecture, is disrupting the semiconductor industry. Traditionally, companies like Intel designed proprietary chip blueprints and sold pre-made chips to customers. Conversely, RISC-V specifications are free for anyone to use to design chips. RISC-V defines the basic functions, known as the instruction set, that a chip can perform to manipulate the values of transistors—for adding numbers, for example. Around 3,100 members, including companies and universities worldwide, collaborate through the nonprofit RISC-V International to develop these specifications. Intel announced a $1 billion fund to support companies building RISC-V chips, and Google wants RISC-V to become a "tier-1" Android architecture.

Worldwide, events like the global chip shortage and Arm's corporate instability are fueling interest in RISC-V. In China, an added urgency is driving RISC-V's adoption. The country wants to reduce reliance on foreign intellectual property and achieve self-sufficiency in chip design, particularly in light of US trade

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restrictions on advanced integrated circuit technologies. Consequently, many Chinese companies that design computer chips but don't make them are considering a switch to RISC-V, which is becoming an increasingly attractive option in the region. In late 2023, the House Select Committee on the Chinese Communist Party suggested the formation of an interagency governmental committee to assess the potential risks associated with RISC-V. This recommendation stems from concerns that the open-source, easily accessible nature of RISC-V might weaken US export control efforts.

AI-Driven Chip Design

Major tech companies like NVIDIA are using AI to improve AI chip design. Designing chips involves placing billions of transistors, and their placement has an enormous impact on cost, speed, and power efficiency. In March 2023, NVIDIA released a paper building on existing research from Alphabet, showing that a combination of AI techniques can find more optimal ways to place large groups of

transistors. As per-transistor costs increase with each new generation of chip manufacturing technology (contrary to Moore's law), NVIDIA chief scientist Bill Dally emphasizes the need for more intelligent design instead of relying on cheaper transistors.

Besides NVIDIA, other major players in the industry are also recognizing the benefits of integrating AI into their chip design processes. For instance, Synopsys and Cadence Design Systems are in a race to provide AI-infused software that companies can use to create their own optimized chips. The integration of AI will help engineers boost the proportion of defect-free chips coming off the production line. Synopsys CEO Aart de Geus said the company intends to invest more in AI tools, especially as the semiconductor industry transitions to chiplets—multiple chips stacked and integrated together to create larger, more complex chips. With major players ramping up AI adoption, the semiconductor industry is poised to benefit from smarter, more automated design.

Custom AI Chips

Instead of relying on traditional chip suppliers like Intel, major tech companies like Meta, Google, and Microsoft are developing their own AI chips and hardware to improve the efficiency, cost, and performance of running AI models. Meta's AI chip is currently focused on inference, not training; the project signals the company's ambition to catch up to rivals in custom AI hardware after previously relying on off-the-shelf CPUs, GPUs, and costly data center redesigns. Microsoft is also reportedly developing its own AI chips to train large language models, reducing reliance on costly NVIDIA GPUs. Microsoft aims to cut costs with these in-house chips; they may be available internally and for OpenAI next year, with future generations planned. The chips won't directly replace NVIDIA but could lower Microsoft's AI costs as the company expands AI in Bing, Office, GitHub, and more.

ARM-based PC Chips

For decades, the personal computing market has run on x86 chips from the likes of Intel and Qualcomm. But ARM architecture,

renowned for power efficiency, is staging a takeover. ARM already dominates mobile. Now major players are bringing ARM to PCs, challenging the x86 foothold. NVIDIA and AMD are making strategic moves by adopting ARM's technology. NVIDIA is venturing into the central processing unit (CPU) arena for personal computers with ARM-based designs. These CPUs, compatible with Microsoft Corp.'s Windows operating system, are anticipated to be available as early as 2025. Similarly, AMD is also reported to be developing ARM-based CPUs for Windows PCs, marking a significant diversification from their traditional product offerings. Microsoft announced plans in November 2023 to roll out its own ARM-based CPU, expected to happen sometime in 2024. The entry of NVIDIA and AMD into the ARM-based PC market poses a new challenge to Intel and Qualcomm. Intel, in particular, faces increased competition at a time when it is striving to reclaim its market share and technological edge. With AMD and NVIDIA joining the ranks of Apple and potentially Microsoft in adopting ARM's architecture, the pressure is mounting on Intel to innovate and compete.

CHIPS

Manufacturing Intelligence

To tap into AI's potential, leading companies like Foxconn and NVIDIA are collaborating to build a new generation of data centers purpose-built for AI workloads. Dubbed "AI factories", these state-of-the-art data centers packed with NVIDIA's latest chips, enterprise software, and other hardware will fuel a wave of AI innovation. Foxconn plans to leverage them to digitize inspections, develop smarter robotics and vehicles, power generative AI applications, and more. The scale of data and model training needed for industrial AI adoption requires specialized infrastructure. While AI chips continue advancing, massive computational horsepower is still essential. Dedicated AI data centers like Foxconn and NVIDIA's can crunch vast datasets into valuable AI assets far faster than typical facilities. Looking ahead, we can anticipate a trend where more data centers will tailor their services to accommodate these demanding AI workloads. Such specialized data centers could emerge as a distinctive offering in the market, characterized by their focus on

AI-specific computing resources. This shift signifies a pivotal moment in the evolution of data centers, aligning them more closely with the rapidly advancing realm of artificial intelligence.

AI factories will offer the vast computational power and customized infrastructure essential for enabling widespread AI adoption.

PERSONAL COMPUTING

PERSONAL COMPUTING

Everywhere Input

Researchers at the University of Michigan have developed a system that can turn everyday surfaces into high-accuracy input devices. Named SAWsense after the "surface acoustic waves" it utilizes, the system employs acoustic sensors to transform everyday objects like couches, tables, and sleeves that respond to commands in the form of taps, scratches, and swipes. Imagine sitting on your living room couch, watching a movie on your smart TV. Instead of reaching for a remote control, you merely tap twice on the armrest of your couch, and the movie pauses. The system works on materials like wood, metal, and fabric with 97% accuracy. These new forms of interaction with computers, through more integrated and personalized interfaces, signal the emergence of ubiquitous and ambient computing. Expanding this concept further, engineers from the University of Colorado Boulder envision a future with dynamic 3D interfaces. Imagine an iPad with a surface that enables you to draw 3D designs; the shape-shifting display uses a grid of soft robotic "muscles," called HASEL actua-

tors. Each of these actuators is a miniature plastic pouch shaped like an accordion that expands to create patterns when electrified. The innovation is precise enough to generate scrolling text and even imitate physical sensation, providing a rare haptic touch to the digital world.
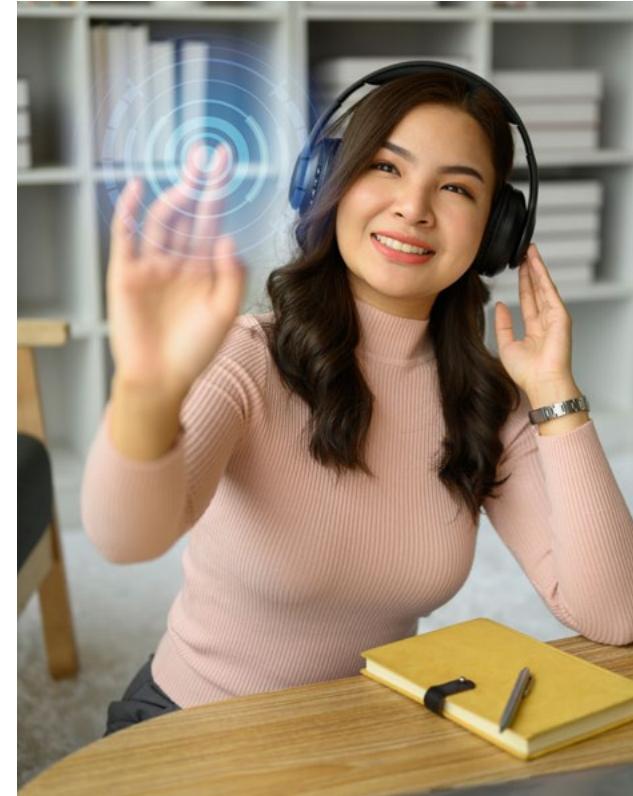
Smart Textiles

An international research team led by the University of Cambridge has developed next-generation smart textiles that are low-cost, sustainable, and produced using standard industrial looms. Unlike previous smart fabrics, these textiles can withstand bending and folding thanks to a process that coats conductive fibers with stretchable materials. The 46-inch woven prototype seamlessly integrates flexible embedded displays. The researchers envision the use of these flexible, eco-friendly smart textiles in various applications such as buildings, car interiors, and clothing. Separately, researchers developed a touch-responsive fabric armband that can act as a flexible keyboard and wearable sketchpad. It uses clear conductive

hydrogel and graphene nanosheets between layers of silk fabric to sense touch in real time. The fabric has been demonstrated to control a computer game and sketch on a computer. The fabric innovations could help drive the widespread adoption of e-textiles and open new opportunities for wearables and smart devices. Scientists also developed the first smart fabric that changes both color and shape in response to temperature and electricity. Made of polymer nano-fibers from recycled plastic, this cost-effective material has extensive potential uses. It represents a milestone in creating practical, affordable smart textiles that can transform our everyday environments.

Human-Centric Pervasive Computing

Pervasive computing, also known as ubiquitous computing, embeds computational capabilities into ordinary objects and environments so that computing can become an invisible and seamless part of everyday life. It's even being integrated onto skin—researchers at Cornell University have developed technologies that allow users to

Pervasive computing will enable people to interact with computers without screens.

PERSONAL COMPUTING

easily construct and use customized on-skin devices for sensing and display. One device, called SkinPaper, uses silicone-treated washi paper that conforms to the body to enable simple on-skin interactions; it could eventually enable a range of promising applications, from health monitoring and personal safety to assistive technologies for the disabled. Another team from Seoul National University and Stanford University developed a spray-on smart skin that uses AI to recognize hand gestures and typing. This spray-on mesh is made of nanowires embedded in a polyurethane coating, and is applied directly to the skin, conforming to its wrinkles and folds. This smart skin allows for seamless gesture recognition without cameras, gloves, or virtual reality systems; it could enable new ways for people to communicate with each other and control devices.

Microsoft researchers are also experimenting with new ways for people to communicate with each other and control devices using our tongues. By combining tongue gestures with gaze, selections occurred faster than just us-ing gaze alone. The researchers have found that the tongue-gaze method can be used as a nonintrusive point-and-click interface.

Wearable AI

AI is changing human-computer interaction, shifting us away from screens, trackpads, and keyboards towards more intuitive, voice-based interfaces. This is giving rise to a new class of lightweight, wearable gadgets and screenless computers that integrate seamlessly into daily life. By reducing screen fatigue and intrusive features, these devices foster a more natural, human-centric approach to technology. A prime example is the newly-launched Humane AI Pin, an OpenAI-powered wearable priced at $699, plus a $24 monthly subscription. Forgoing traditional app interfaces, this 34-gram device focuses solely on voice interactions. Users access information and perform tasks by speaking to the Pin's built-in microphone. By stripping down the technological interface, Humane aims to create a streamlined, human-like experience. Another device is the Rewind AI Pendant which captures real-world

As AI enables more natural computer interaction, there are increasing use cases for compact, perhaps screenless wearables.

PERSONAL COMPUTING
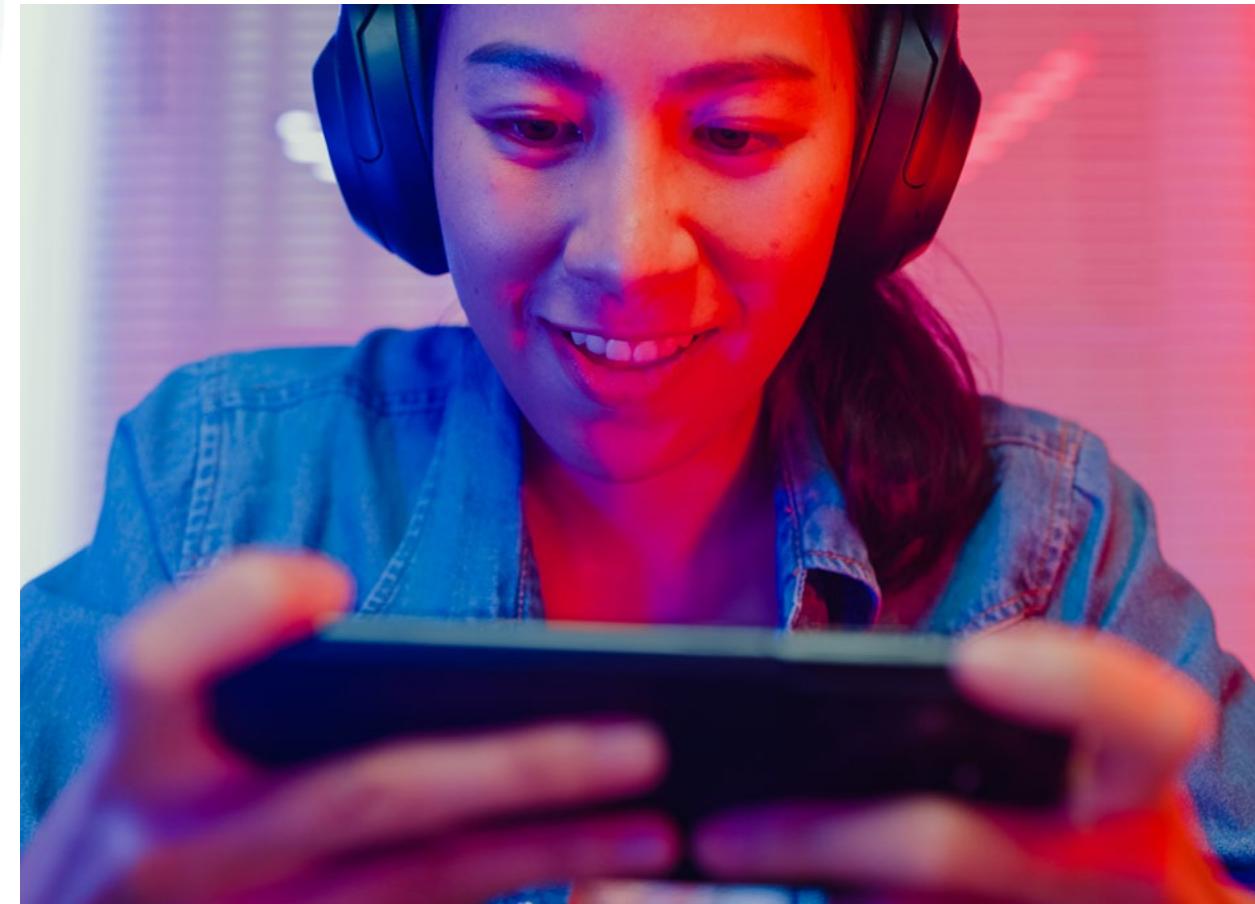
conversations, storing encrypted transcripts and audio locally on the user's phone. Beyond recording, Rewind's platform searches transcripts, generates meeting summaries and analyzes speech patterns. Essentially, the Pendant serves as a personalized assistant harnessing environmental information to support the user. Both the Humane Pin and Rewind Pendant epitomize the shift towards invisible, assistive technology that facilitates life's tasks and interactions much like a helpful human companion would. This evolution in form and function represents a paradigm shift, integrating technology more seamlessly while making it feel more intuitive and human-centric.

The Convergence of Gaming Devices for Productivity

The portable PC market is gaining momentum, fueled in part by interest in dedicated gaming devices. While many portable PCs were initially targeted at gamers seeking power and performance on the go, they show potential for other applications. This potential is reflected in a leaked video showing Microsoft exploring an optimized "Windows handheld mode" for gaming devices like the Steam Deck. The video shows a prototype with a custom game launcher, controller-friendly keyboard, and floating taskbar designed for touchscreens. If developed further, this could enable handheld PCs to run Windows and games from multiple stores.

Going in the opposite direction, a developer separately created a way to use Steam Deck controls in Windows, suggesting the gaming-centric design could suit more general purposes. Though preliminary, these signs indicate the promise of handheld PCs for both gaming and productivity. They could serve enterprise and business users as ultralight yet high-performance secondary machines or bring-your-own-device options. Their versatility, comfort with both touch and keyboard input, and suitability for entertainment and productivity make them an intriguing form factor for multiple use cases.

Handheld gaming devices pack impressive computing power that could be utilized for AI-assisted productivity tools.

SCENARIOS

Silent Signals

A dense forest in a hostile territory: Night has fallen, and visibility is limited. A special forces team is tasked with rescuing hostages from a heavily guarded compound. Their mission depends on stealth and silent communication, which is why they're equipped with the latest spray-on smart skin technology.

The team gathers at a concealed location near the target and applies the smart skin mesh to each team member's hands. They will use hand gestures to communicate with each other and the remote tactical operations center.

They move silently toward the compound. The team leader raises his hand in the "hold" signal, and the team freezes. Using more hand gestures, he conveys there are enemy guards nearby. That gesture data also makes the tactical operations center immediately aware of the team's status—without any verbal communication or interceptable radio communications that would give away their location.

The team leader signals that he needs feedback from the overhead drone to check movement out of his line of sight. He receives silent haptic feedback in his gloves; the staccato pulse vibrations confirm that there is movement, and the opposing forces know the soldiers are there. He signals to his team to execute plan B. The element of surprise is lost but the technological advantage remains.

The primary benefit of this technology lies in enabling communication where radio transmissions and verbal commands might otherwise betray position. These silent gestures serve not only for on-the-ground communication between team members but also facilitate remote interaction with tactical operations, providing a discreet and untraceable channel for vital information exchange.

PERSONAL COMPUTING

Right to Repair

The Right to Repair movement has rapidly gained momentum across the United States, with several states passing laws to empower consumers and independent repair shops in the face of repair restrictions imposed by manufacturers. This addresses growing concerns that companies severely limit access to replacement parts, tools, and service information for items like electronics and machinery, forcing reliance on often costlier authorized service providers. California is the latest state to enact Right to Repair legislation, following New York, Colorado and Minnesota over the last year. The bill guarantees consumer access to the components, manuals and diagnostic software needed to service and repair electronic products. Significantly, Apple expressed support for the law despite past lobbying efforts against repair reforms. This shift came amidst criticism of Apple for utilizing software locks that prevent functioning hardware from operating fully unless repaired by Apple technicians using strictly Apple components.

However, challenges linger regarding adherence to the spirit of the laws. For example, Apple's recent iPhone 15 contains proprietary software locks that inhibit non-Apple replacements, triggering warning messages or disabled features. Repair authority iFixit. com has highlighted how these exclusive locks undermine Right to Repair progress by limiting choice and affordability around genuine repairs.
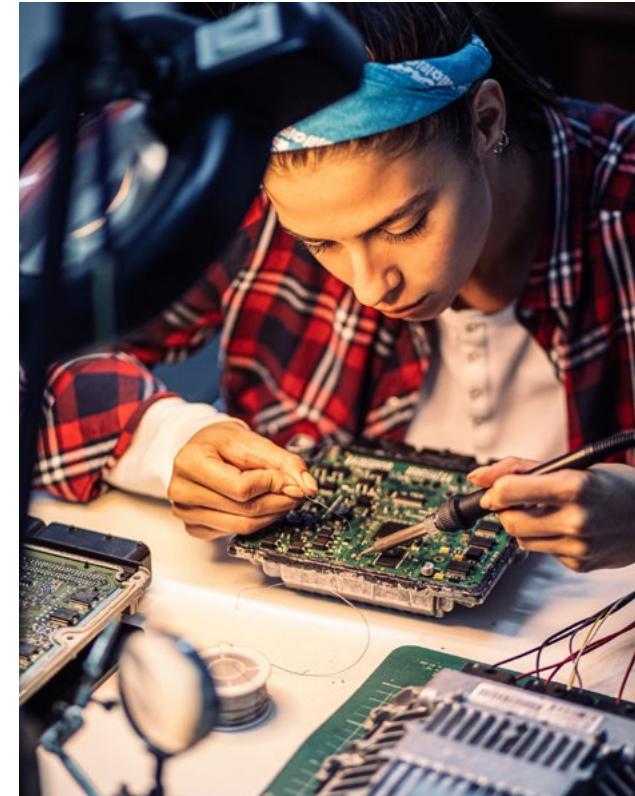
Maximum Cooling to Minimize PC Size

There are traditionally two cooling methods for PCs: active cooling with fans and passive cooling without fans. A startup called Frore Systems has developed a novel third method: an innovative solid-state device called AirJet that provides active cooling in a quieter and more compact form factor. AirJet's vibrating membranes in the chip create suction and push high-velocity air to cool the copper heat spreader below the chip. Frore Systems found PCs equipped with AirJet performed better than those without while running intensive graphics stress tests: 9-11 frames per second compared with barely one frame per second. Because adding more AirJets doesn't make the device thicker or noisier, in the future PCs equipped with the technology could be quieter, thinner and have bigger batteries. The company sees potential for AirJet in gaming smartphones, 4K webcams, stick PCs, storage devices, doorbell cameras, and LED light bulbs.

LLMS as Operating Systems

In November 2023, AI luminary Andrej Karpathy introduced a groundbreaking concept that could redefine our interaction with computers: an operating system fundamentally powered by a LLM. The LLM would not just be an add-on feature; the LLM would function as the core kernel of the OS. Routine tasks could be executed with an unprecedented level of sophistication, automating operations that once required manual intervention. The user interface in this envisioned OS departs from traditional graphical user interfaces (GUIs) and command-line interactions. It embraces a more intuitive, natural language–based interface. Users can interact with their computers through conversa-

The right to repair advocates for allowing customers and independent shops to fix their own devices independently of the original manufacturer.

PERSONAL COMPUTING

tional commands, inquiries, or requests for specific tasks. The LLM, understanding these requests, would perform a series of actions to accomplish the desired outcomes. This concept has moved beyond theory into practical application, as demonstrated by Jesse Lyu, CEO and founder of Rabbit. Lyu launched the R1, a compact device about half the size of an iPhone, running on Rabbit OS—an operating system grounded in a LLM. Rabbit OS functions as a universal app controller, akin to systems like Alexa or Google Assistant, yet it offers a unique twist. It simplifies user interaction by removing the need to navigate through multiple apps or perform repetitive logins. Instead, users can directly communicate their needs to the device, and R1, understanding these natural language requests, efficiently executes the desired tasks.

Personal Computers on Wheels

Major automakers are transforming their cars into personal computers on wheels. Intel recently introduced a new AI-enhanced system-on-a-chip specifically for cars, with Zeekr being the first to implement this technology.

Intel's move into the automotive sector is marked by the introduction of the "first-generation AI-enhanced software-defined vehicle system-on-chip." This development is part of its broader strategy to integrate AI across various platforms, emphasizing the importance of personal computing devices, including cars, as secure environments for AI processing compared to cloud-based solutions. Volkswagen is another example, showcasing its integration of the AI-based ChatGPT in its IDA voice assistant in vehicles. Volkswagen plans to standardize this feature in many of its production vehicles in 2024, being the first volume manufacturer to do so. BMW is also reimagining the in-car experience. The company is enhancing its vehicles with streaming video, gaming options, and augmented reality, powered by AI-driven voice assistants, using Amazon's Alexa technology as a base. This assistant is designed to interact in a more human-like, conversational manner, offering both information about vehicle functions and control over some of these functions.

These advancements signal a paradigm shift in vehicle interfaces, aligning them more closely with digital lifestyles. As people grow accustomed to constant access to entertainment and information, car manufacturers are acknowledging the transformation of cars into multifunctional personal devices. These vehicles are now platforms for productivity, social connectivity, and leisure, marking a pivotal evolution in the automotive industry and fundamentally changing how we interact with our vehicles.

Since AI enables natural language input, we can now communicate more effectively with computers in vehicles, making personal computing accessible wherever we choose, including in our cars.

BIOLOGICAL COMPUTING
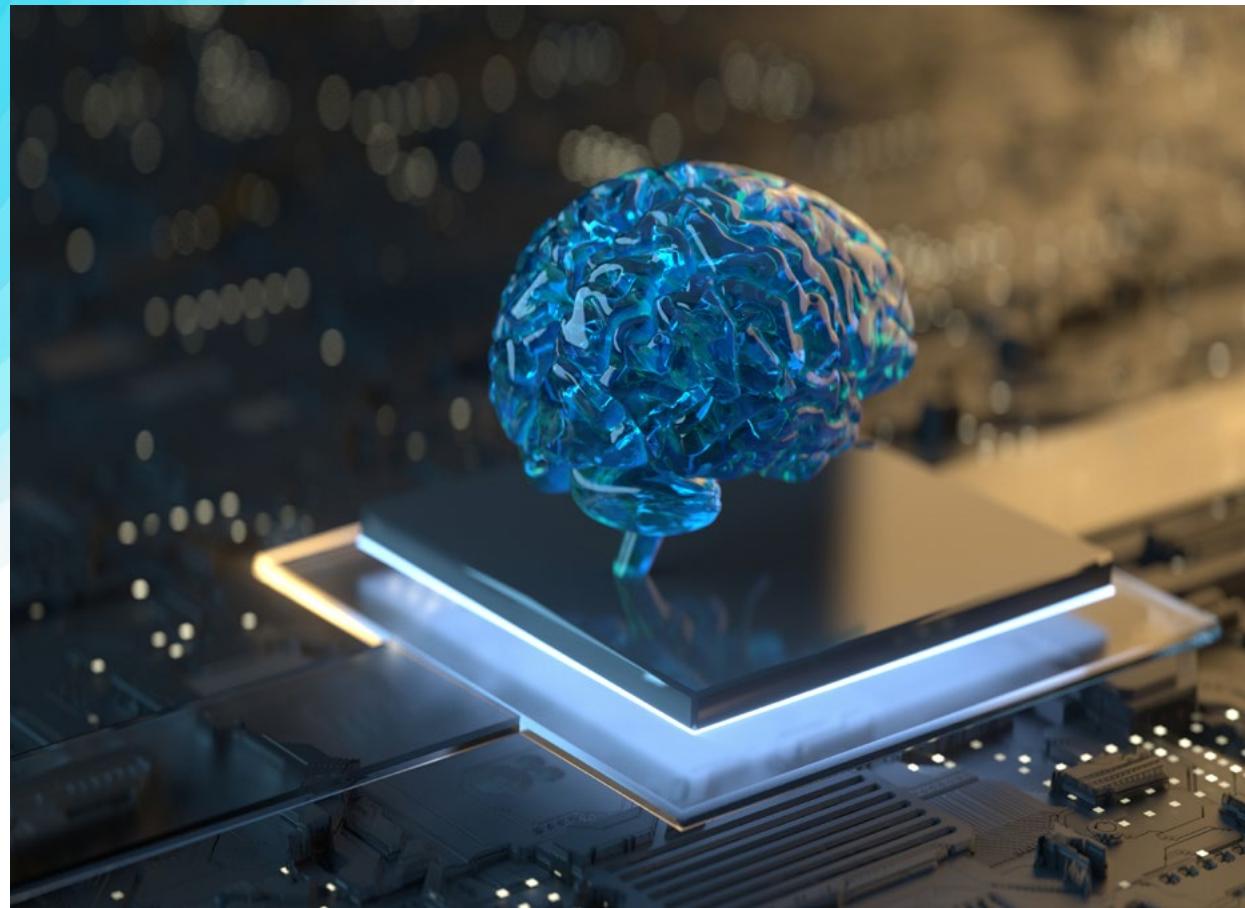
BIOLOGICAL COMPUTING

Neuromorphic Computing

Researchers are experimenting with new architectures to make computers faster and more energy efficient. One such approach is neuromorphic computing, which is inspired by the most energy-efficient computer on earth: our human brains. Where conventional computers must run commands sequentially, laboriously moving data back and forth between the memory and processor, neuromorphic chips simultaneously store and process information. Intel's neuromorphic chips have already achieved up to 1,000 times higher energy efficiency compared to general-purpose chips and excel at detecting sensory input like gestures, sounds, and even smells. These chips have enabled a variety of systems, from artificial skin that can sense touch to an "electronic nose" capable of identifying scents from explosives. Other large-scale neuromorphic architecture projects include IBM's TrueNorth, SpiNNaker, BrainScaleS, and Tianjic.

While neuromorphic computers have not yet replaced conventional hardware, recent research shows promise. For instance, researchers at Sandia National Laboratories have demonstrated that approximation algorithms can be implemented on neuromorphic hardware to efficiently solve complex optimization problems. Separately, a joint team from Purdue, USCD, and ESPCI is working on research that underscores the need for materials vastly different from silicon, which can naturally replicate synapses and neurons. The team's breakthrough involves using vanadium dioxide, a material exhibiting both synaptic and neuristor capabilities. They've discovered a way to visually monitor changes within this material, revealing that memory accumulates across the entire sample. This insight opens up new possibilities on how and where to control this property, potentially enhancing the synaptic behavior of neuromorphic materials.

Neuromorphic computing mimics the neural structure and processing method of the human brain to create more efficient computer systems.

BIOLOGICAL COMPUTING

Organoid Intelligence

The key distinction between biocomputers and neuromorphic computing resides in the systems and elements they each seek to replicate and harness. Neuromorphic computing aims to mirror its efficiency in the design of computing systems while biocomputing looks to utilize the inherent capabilities of biological materials or systems for information processing.

Researchers at Johns Hopkins University recently outlined a vision for the future of biocomputers, powered by human brain cells, in a paper published in the journal Frontiers in Science. Led by Thomas Hartung, the team outlined a roadmap for "organoid intelligence," aiming to bring biological computing to life using 3D cultures of human brain cells. These tiny 3D organoids, no larger than the point of a pen, are equipped with neurons and circuitry capable of supporting fundamental functions such as learning and memory. Organoid intelligence holds significant potential for augmenting computing capabilities while concurrently addressing the escalating energy consumption demands driven by advancements in artificial intelligence and supercomputing. Despite traditional computers' ability to process calculations at speeds far surpassing human capabilities, human brains demonstrate superior performance in complex decision-making tasks, such as differentiating between a dog and a cat. Running AI on organoids could be the key to achieving human-like complex decision-making.

Furthermore, running AI on organoids would be more energy efficient. As AI systems like self-driving cars become more complex, they will require massive amounts of computing power and energy; for instance, self-driving cars are estimated to use up to 20% more energy than conventional cars. In the next decade, computers utilizing biological hardware could begin to address the increasingly unsustainable energy consumption demands.

Living AIs Solve Equations

Indiana University researchers have crafted an organoid with lab-grown human brain cell clusters capable of solving elementary math tasks. Named Brainoware, this system harnesses living brain tissue for computations, potentially lowering the energy demands of sophisticated AI platforms. In initial tests, the brain organoids could solve a complex math problem called the Hénon map, demonstrating their ability to perform computations. While the organoids are limited in size due to a lack of blood vessels, the research shows promise for using living

hardware to address the energy and hardware limitations faced by increasingly complex AI systems. It should be noted that the Brainoware research has been published on the preprint server bioRxiv, though not yet in a peer-reviewed journal.

BCI + Robots

MIT Media lab and Boston Dynamics are collaborating to build the first brain-controlled robot. The project, called Ddog, combines Boston Dynamics' Spot robot with an EEG brain-computer interface system called AttentivU that uses wireless glasses to measure brain activity and eye movements. These signals are then interpreted to control the Spot robot in real time. Ddog builds on an existing app called Brain Switch, which allows people with limited mobility to communicate nonverbally with the help of caregivers; it's completely wireless and autonomous, running on two iPhones without the need for electrodes or heavy computing equipment. Ddog conveys the promise of combining neurotechnology and robotics to empower users and assist them in meaningful ways, such as by deliver-

BIOLOGICAL COMPUTING

ing groceries or other objects, moving furniture, or retrieving items using Spot's robotic arm. Because the system is highly mobile and practical for in-home use, it has significant applications for less mobile populations, including those with disabilities and the elderly. As populations continue to age, human workers may not be able to provide assistance to all those who need it. Systems like Ddog show how robots can help fill in the gaps, providing autonomy and a better quality of life for users.

Soft Implantables

Conventional brain implants are rigid, making them ill-suited for the soft tissues of the brain. To address this, engineers at Rice University developed an alternative: ultraflexible nanoelectrodes that can achieve connections with minimal harm. These tiny, flexible implants deliver targeted electrical pulses that closely match natural neural signaling. With their precision and biocompatibility, the flexible nanoelectrodes could enable new therapies like sensory or motor prosthetics. Separately, Harvard researchers are developing a soft electrode using natural hydrogels

extracted from seaweed. These gels possess the same pliability and responsiveness as the brain itself. Anchored to the organ's movements rather than resisting them, hydrogel electrodes could foster connections that stand the test of time. The researchers note that soft, biologically based electrodes may permit more natural cell contact and integration than their stiff, metallic counterparts.

Conventional implants have another limitation: they are temporary. As the soft brain moves, it repeatedly collides with rigid electrodes and gets damaged. In response, scar tissue builds up around the implant, cutting it off from surrounding neurons. Within a few years, this scarring isolates the device to the point that it must be replaced. Researchers at Linköping University developed a solution: Rather than building an electrode outside the brain and forcing it in, they designed an injectable gel. Once inside the brain, the gel solidifies into a conductive, yet pliable, electrode. Because this electrode moves with the brain, it avoids the damage that

leads to scarring around the implant. The researchers' biomimetic approach, allowing the brain's own movements to shape the implant, holds promise for crafting neural interfaces that last as long as they are needed.

Nanowire Networks Emulate Our Memories

Researchers at the University of Sydney built nanowire networks that physically mimic the structure of the human brain. These networks—composed of mesh silver wires—exhibited both short-term and long-term memory, which suggests that brain-like learning and memory could potentially be replicated in non-biological systems. When information in the nanowire network is repeatedly reinforced, it becomes consolidated into long-term memory, similar to how our brains convert short-term memories into long-term memories. This research expands on previous work showing nanotechnology can be used to build brain-inspired devices with neural network-like circuits and synapse-like signaling; the results suggest the essence of human-level intelligence could arise from physical structures.

Imitating Human Perception: Advancing Computer Vision

Humans are good at predicting how objects and people will move. When we pass a person on the sidewalk, we have a good model of their trajectory; when we are stopped at a red light at an intersection, we can reasonably predict which oncoming cars will turn. This is because we exhibit "perceptual straightness"—the ability to perceive dynamic visual information and transform it into a stable mental representation. Unlike humans, computer vision models typically lack this ability, which is a problem if we want to interact with mobile robots or autonomous vehicles. But that could change, after MIT researchers identified a property that helps computer vision models learn to represent the visual world in a more stable, predictable way. The researchers found that training computer vision models using adversarial training, which makes them less sensitive to small errors in images, improves their perceptual straightness. They also found that the task a model is trained on affects its perceptual straightness: It's more effective to train models on abstract tasks like image

BIOLOGICAL COMPUTING

classification than fine-grained tasks like pixel-wise classification. Understanding perceptual straightness in computer vision could help make robot/human interaction safer since better computer vision would help robots better predict trajectories of people and vehicles.

Storing Images in DNA With Biological Camera
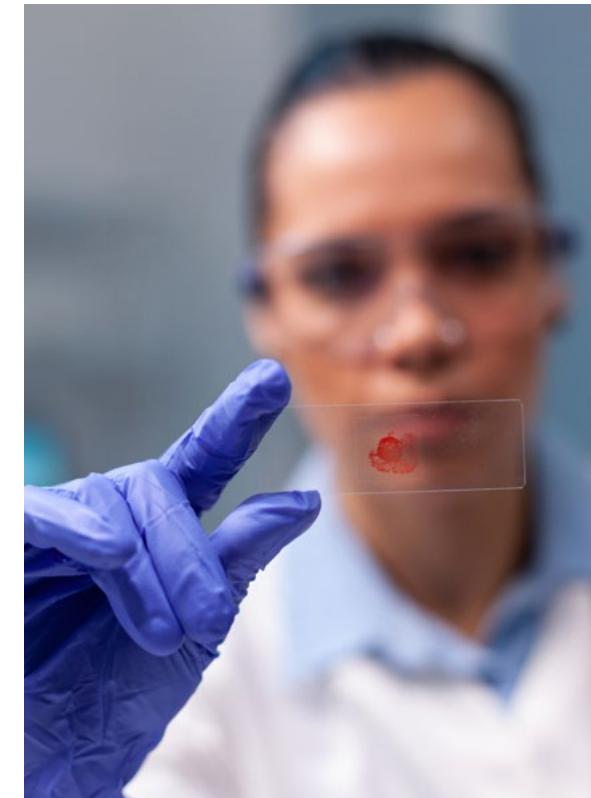
Researchers are exploring DNA computing as an alternative storage medium to resource-intensive data centers, due to DNA's immense storage capacity and long-term stability. However, current DNA storage research focuses on synthesizing DNA strands outside of cells, an expensive, complex, error-prone process. To overcome this challenge, researchers at the National University of Singapore turned to live cells containing DNA that act as a natural "data bank." The system—called BacCam—emulates a digital camera's functions using biological components. "Imagine the DNA within a cell as an undeveloped photographic film," explained associate professor Chueh Loo Poh, who led the research. "Using optogenetics—a

technique that controls the activity of cells with light akin to the shutter mechanism of a camera, we managed to capture 'images' by imprinting light signals onto the DNA 'film.'" BacCam can capture and store multiple images simultaneously using different light colors, and the images were marked with barcoding for labeling purposes. Machine learning algorithms organized, sorted, and reconstructed the images, constituting a "biological camera" that mirrors a digital camera's data capture, storage, and retrieval capabilities. Importantly, compared to prior DNA storage methods, the team's innovative system is easily reproducible and scalable.

DNA-Based Molecular Computing

Traditional computer hardware is limited in its ability to interface with living organs, and computerized implants require a constant supply of electricity and cause damage to soft tissue. Researchers at the University of Minnesota have developed a biocomputing platform to overcome both of these challenges. The Transcriptional RNA Universal Multi-Purpose GatE PlaTform, or "Trumpet,"

uses DNA molecules and biological enzymes to perform logic gate operations, the building blocks of all computer programs. Unlike live cell biocomputing, Trumpet is nonliving, so it avoids evolutionary constraints on live cells and signal leakage issues. The researchers demonstrated they can use Trumpet to build all universal Boolean logic gates (e.g., "and," "or") and also built a web-based platform for designing Trumpet gates. The lead author of the study and Ph.D. candidate Judee Sharon is exploring the use of the Trumpet platform to develop biomedical applications for early cancer diagnosis. Another promising area is "theranostics"—the fusion of diagnostics and therapeutics—and Trumpet could be used to detect conditions like low insulin levels. By harnessing the computational power of biology, Trumpet could transform how diseases are diagnosed and treated in the coming decades.

DNA-based molecular computing uses the unique properties of DNA molecules to perform computations, offering a potential for massively parallel processing and storage capabilities.
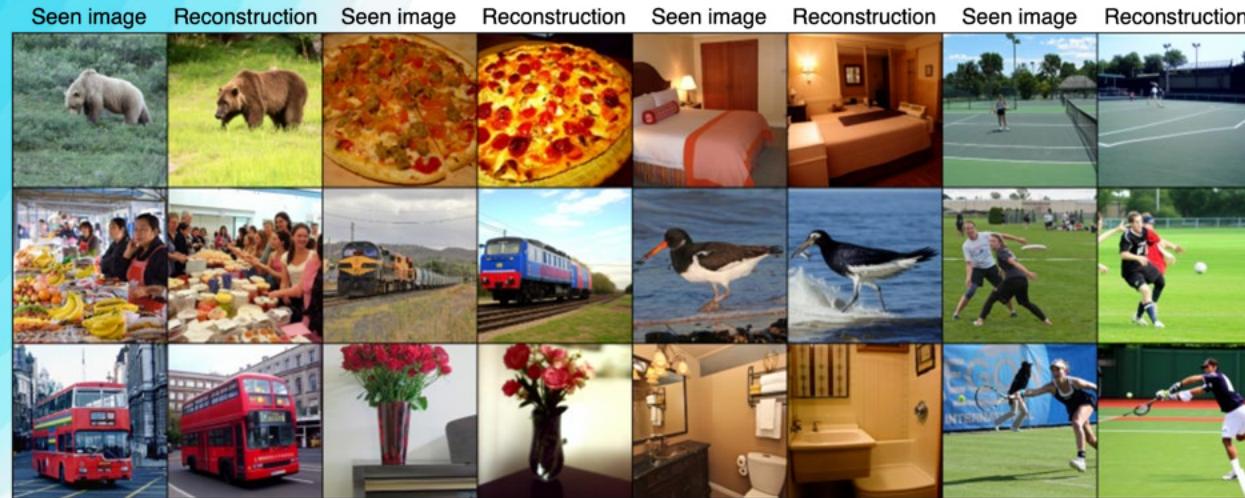
BIOLOGICAL COMPUTING

Image Reconstruction

Recent advancements are allowing us to glimpse inside the human mind, offering a way to reconstruct thoughts and images. Although still in its early stages, this technology shows promising potential. Consider the two images: the first, known as the "seen image," is a picture of what a human saw with their eyes; the second, called the "reconstruction," is what a machine learning model thinks the person saw, based only on a brain scan. State-of-the-art brain image reconstruction techniques made these results possible.

In the rapidly growing field of fMRI reconstruction, new projects aim to improve performance, interpretability, and versatility. Diffusion-based methods have already created images from pure noise, with breathtaking results seen in projects like MindEye, designed to retrieve and reconstruct viewed images from brain activity. It can map brain activity to high-dimensional spaces, allowing image reconstruction using generative models. Compared to other methods, MindEye achieves top performance in both reconstruc-

tion and retrieval, even among highly similar images. Another exciting development is Mind-Video, which reconstructs human vision in video form from continuous fMRI data. By learning from the brain's spatial and temporal information, Mind-Video can create high-quality videos at varying frame rates. Together, these innovations are breaking new ground in understanding human cognition and unlocking our ability to visualize the mind's content. They mark an exciting step toward a future where thoughts might be visually represented and no longer confined within our skulls.

The seen image is what is physically presented to a person, while the reconstruction is the image generated by AI from analyzing the person's brain FMRI scan.

SCENARIOS

The Digital DNA Walkers

The world is facing an unprecedented explosion of data. Conventional storage methods are energy intensive and expensive, leading companies to turn to an unconventional solution: human beings as walking, living data storage devices. A tech startup named GeneBank offers individuals a unique opportunity to monetize their DNA. By becoming a "Data Carrier," they can lease space within their DNA to corporations, research institutions, or private clients. The procedure is simple, painless, and perfectly safe, according to GeneBank's marketing materials.

Given the value of the data stored within human carriers, insurance companies start offering specialized DNA data insurance as part of their health insurance plans. These policies cover potential data loss, corruption, or unauthorized access. Data Carriers are required to undergo regular check-ups to ensure the integrity of the information they carry, and premiums are tied to the volume and sensitivity of the data. This is an ideal side hustle for anyone engaged in the gig economy.

SCENARIOS

AI + OI + LOE

Organoid intelligence has become the forefront of computational evolution, merging human-like decision-making capabilities with the speed of traditional computers. However, the ethical dilemma around these brain organoids sparked global debate and protests, leading to a radical decision by a pioneering company called NeurAI.

Facing mounting pressure from ethical watchdogs, human rights activists, and protesters equating organoid-powered AI with slavery, NeurAI sought an innovative solution: relocating manufacturing and computation to outer space, outside any specific country's jurisdiction—and legal or ethical boundaries.

Through the move to space, NeurAI capitalizes on the ease of creating organoids in microgravity—in microgravity they form more uniform structures. It lets customers access the organoid powered AI through NeurAI's cloud platform, The Celestial Mind. This network becomes globally accessible, providing unparalleled computational power for applications ranging from scientific research to business analytics.

ADVANCED LARGE SCALE COMPUTING

ADVANCED LARGE SCALE COMPUTING

Exascale Supercomputing

Exascale computers are digital computers that are much more powerful than today's supercomputers but different from quantum computers. While quantum computers use unique quantum properties to perform computations, exascale computers use the same transistor-based architecture as today's most powerful computers, just taken to the extreme. In 2022, the world's first exascale computer, known as Frontier, came online at the Oak Ridge National Laboratory. Frontier can perform calculations seven times faster and hold four times more data in memory than previous supercomputers. Two more exascale computers, El Capitan and Aurora, are expected soon. All three are projects of the US Department of Energy and its National Nuclear Security Administration to run the calculations that help maintain the nuclear weapons stockpile. The supercomputers also exist to solve intractable problems in science. For instance, exascale computers could refine hurricane predictions in meteorology or simulate molecular structures for the pharmaceutical industry. In medicine, exascale comput-

ers have already analyzed genetic mutations of SARS-CoV-2, the virus causing COVID—reducing the calculation time from a week to a day—to comprehend how these genetic variations impact the virus' infectiousness.
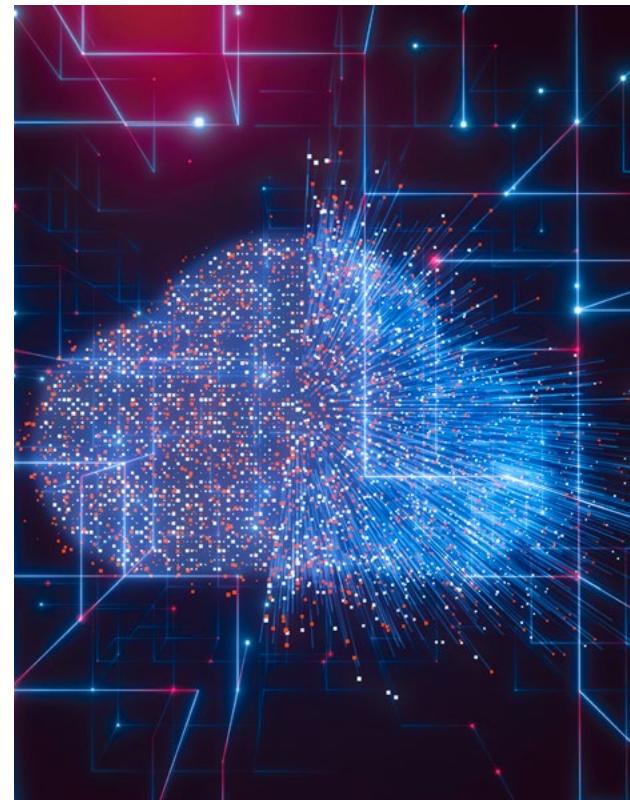
Supercloud

Cloud computing holds value in part because of its user-friendly nature—it provides an abstraction layer over storage, processing, and applications, eliminating the need for users to handle hardware and software maintenance. However, in an era where businesses manage multiple cloud environments, there's a reemergent need for another abstraction layer to simplify management. Enter the supercloud. First coined in a 2017 study by Cornell University, the term refers to an added abstraction layer that operates independently of the underlying cloud platforms. This layer allows various cloud environments to interact and function as a cohesive whole, facilitating the effortless movement of software, applications, and data across different cloud ecosystems. It lets companies maintain service contracts

with various providers such as AWS, Google Cloud, and Azure while ensuring a consistent user experience; it means that developers don't need to repeatedly configure a new app with security features and various operating systems for every cloud platform their organization employs. Supercloud also implies that end users can transfer data and applications smoothly across clouds and data centers without hindrance. Companies like Snowflake are already offering data services that connect to major hyperscale cloud providers, but the concept of the supercloud is still far from mainstream. Hurdles remain, such as the dissolution of closed ecosystems and issues surrounding data gravity, security, backup, and monitoring.

Serverless Cloud

Serverless cloud computing is a transformational approach to cloud services. The term is often misunderstood—serverless computing still relies on servers. However, the cloud provider takes on the responsibility of managing and operating those servers. Traditionally, cloud computing requires renting

Supercloud is a cloud architecture that integrates services, data, and applications across multiple clouds for greater flexibility, scalability, and interoperability.

ADVANCED LARGE SCALE COMPUTING

virtual machines (VMs) from a provider; the user must handle security, failure recovery, and overload prevention for those VMs. Serverless computing revolutionizes this model by shifting all server management duties to the cloud provider. This concept is exemplified by Amazon Web Services' (AWS) recent serverless innovations. For instance, AWS introduced Amazon Aurora Limitless Database, a part of Amazon Aurora now in preview. This service scales to handle millions of transactions per second and manages vast data volumes. It functions by automatically distributing data and queries across multiple serverless Aurora instances, relieving customers from managing a complex database system. Other serverless innovations from AWS include Amazon ElastiCache Serverless, which enables creating highly available data caches without manual setup. Additionally, Amazon Redshift Serverless proactively adjusts resources based on workload patterns, no manual tuning needed. Microsoft, IBM, and Cloud Flare also have solutions in this space. These innovations in moving the responsibility of server management from the user to the cloud provider greatly simplify usage while allowing for flexible scaling.

Alternative Energy for Data Center

The monumental computational requirements of advancing AI could catalyze a nuclear power renaissance. A job posting from Microsoft hints that the company is exploring using small modular nuclear reactors (SMRs) to meet its AI and cloud computing needs. SMRs promise cheaper, faster modular construction compared to traditional nuclear plants, which are often over-budget and delayed. Microsoft's approach was hinted at further in the fact that they already have a deal to buy Clean Energy Credits from Ontario Power Generation, which is on track to be the first utility to deploy an SMR in North America. Companies like Rolls-Royce, Last Energy, NuScale, Oklo, and TerraPower (backed by Bill Gates) are also developing various SMR models. Similarly, Kärnfull Next in Sweden plans to use SMRs to power data centers. The pivot towards nuclear energy, particularly next-generation SMRs, is a strategic response to the dual challenges of meeting the high energy demands of AI and achieving climate goals. Microsoft's exploration of this avenue, including seeking expertise in SMR rollout, reflects a broader industry trend.

Photonic Computing Architecture

Machine vision allows computers to interpret images similar to how the human eye and brain "sees," but even faster and more accurately. Researchers at Tsinghua University are proposing a photonic computing architecture to enhance this capability. Current photonic computing is limited by slow memory access. The researchers' new architecture combines parallel spatial computing (simultaneous tasks) and temporal computing (fast sequential tasks) in a "3D spatiotemporal plane." They've also developed a new training system to optimize both the physical system and the network model. In doing so, they've been able to speed video processing 40 times with 35 times fewer parameters than traditional systems. The researchers believe their new system could be the first step toward ultrafast machine vision that isn't held back by the slow speeds of computer memory, with applications in unmanned systems (like drones or autonomous robots), autonomous driving, and ultrafast science.

Photonic Cellular Automata

Caltech researchers have leveraged optical hardware to create cellular automata, computer models consisting of cells that can live, die, reproduce, and evolve. From these simple rules emerge complex behaviors that can be used to perform computing tasks. For instance, cellular automata can be used to generate random numbers, conduct physics simulations, and do cryptography. Cellular automata are ideal for photonic technologies because information processing happens locally (cells only interact with immediate neighbors), eliminating much of the hardware that makes photonic computing difficult. Furthermore, the high bandwidth of photonic computing allows cellular automata implemented with light to run extremely fast, up to three orders of magnitude faster than digital computers. In Caltech's photonic computing
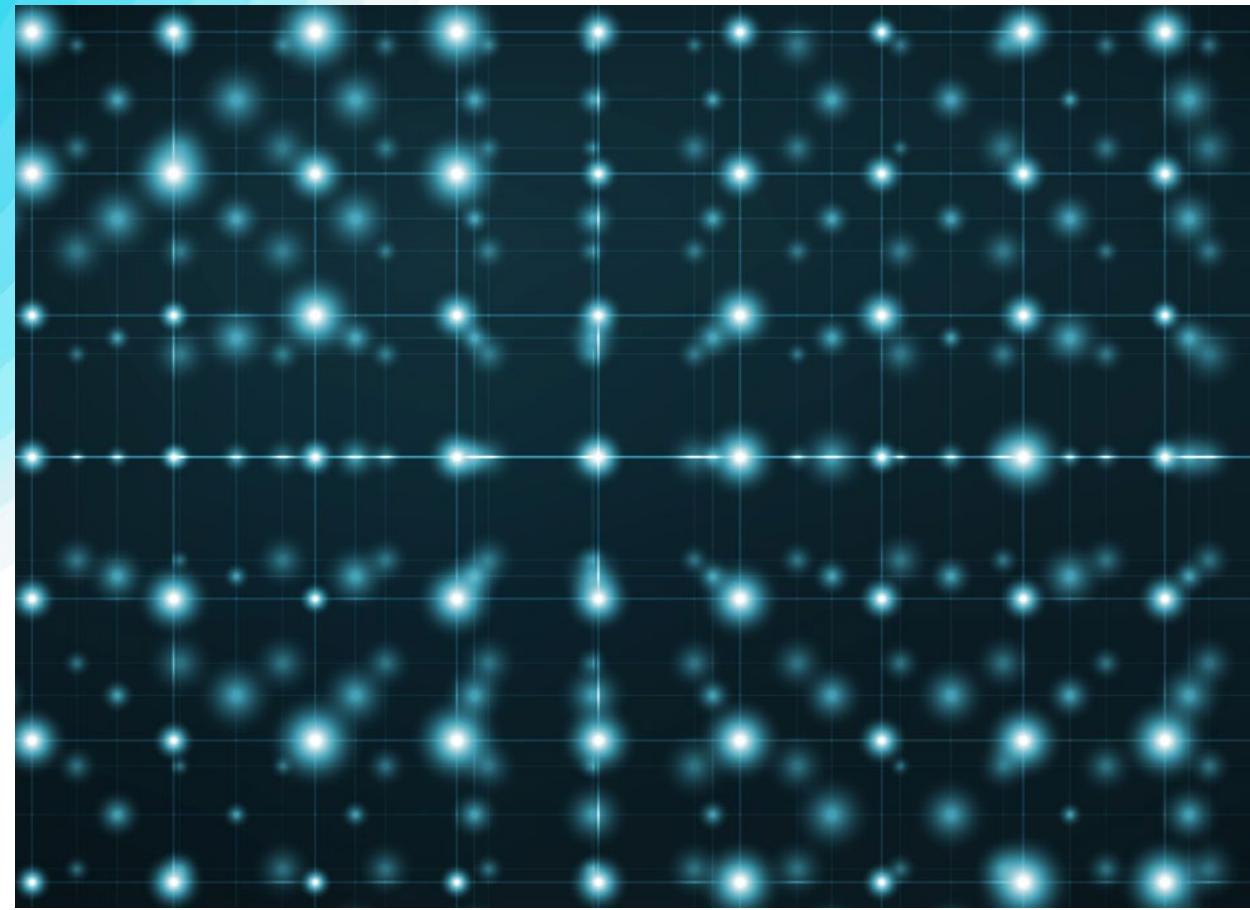
ADVANCED LARGE SCALE COMPUTING

device, the cellular automata cells are pulses of light interacting on a hardware grid to process information without the slowdown caused by digital computing layers. This technology could enable next-generation computers that perform tasks far more efficiently than digital electronic computers.

Magnon-based Computation

Traditional computing architectures separate processors and memory, requiring energy-intensive signal conversions to move data between components. This bottleneck, known as the memory wall, slows computation and wastes energy. However, a team led by Dirk Grundler at the Swiss Federal Institute of Technology is developing an alternative computing approach using magnonics to overcome this limitation. Magnonics, an emerging field that aims to enable faster, more efficient information technologies, uses magnons, which are quanta of spin waves that can encode and transport data in magnetic materials without electron flows or Joule heating. The researchers harnessed this property to design a magnonic computing

device that enables in-memory computation, where processing and memory occur in the same physical location. With memory and processing occurring in the same place, the magnonic technique could significantly reduce computing's energy consumption by overcoming the memory wall. Theoretically, it could enable terahertz data processing speeds, far exceeding today's gigahertz processors. While still requiring optimization, this approach shows promise for more sustainable computing through wave-based in-memory processing. By attracting researchers to magnonics, the team hopes to spur interest in this field.

Magnon-based computing utilizes magnons—quasiparticles associated with the collective spin wave excitations in magnetic materials—to process and store information, offering a potential pathway to low-power, high-speed computing.

QUANTUM COMPUTING

QUANTUM COMPUTING

Quantum Advantage

Quantum advantage, also known as quantum supremacy, is the theoretical point when quantum computers outperform classical computers by solving problems more efficiently, accurately, or faster. In June 2023, IBM Quantum and University of California, Berkeley researchers unveiled a major step forward in the quest for quantum supremacy. In an experiment, they both executed increasingly complex physical simulations—IBM Quantum on the 127-qubit IBM Quantum Eagle processor, and UC Berkeley using state-of-the-art classical approximation methods on supercomputers. At certain computational levels, the traditional supercomputer's brute-force methods failed while the quantum processor continued to deliver solutions. Even when classical solutions weren't possible, advanced classical approximation methods were used for comparison with quantum outcomes. It was observed that the quantum processor's results were more accurate than the classical approximations, marking a significant advancement in quantum computing. For Darío Gil, senior vice president and director of IBM

Research, this achievement marks the first instance of quantum computers modeling a physical system in nature beyond the capabilities of leading classical approaches. According to him, this milestone signifies the advent of a new era of practical utility for quantum computing. Although IBM's experiment doesn't serve as definitive proof, it offers a valuable data point suggesting that by using error mitigation, current quantum computers can provide benefits much sooner than previously anticipated.

Global Quantum Competition

Both the US and China are competing to become the global leader in quantum—a position that would enable the leading country to threaten adversaries' various information infrastructures by cracking existing encryption methods, building impenetrable encrypted communication networks, and developing highly precise sensors. Furthermore, the first country to commercialize quantum would have enormous market power; by 2035, the global market value of quantum computing alone is predicted to reach $1 trillion.

Though both countries purport to be the global quantum leader, between 2011 and 2020, the US led in quantum computing publications and secured double the number of highly cited publications compared to China, according to Foreign Policy. US quantum computing companies also reportedly received 30 times more funding than their private Chinese counterparts, though significant investment is being made in government-backed research in China. But China is moving quickly: Despite trailing in quantum computing, the country leads the world in quantum communications, a subfield that promises ultra-secure data transfers. And Chinese quantum researchers claim to have developed an algorithm that can break public-key encryption, much earlier than anticipated. Though these claims have been met with much skepticism, if valid, they would imply a significant quantum advantage for China.

Notably, following controls on semiconductors, the US Commerce Department seems to be turning its attention to quantum

computing, expressing concern that China could weaponize this emerging technology. It is anticipated that export controls on quantum computing hardware, error correction software, and provision of cloud services to Chinese entities will become the next battleground in the US-China tech war. Despite this competition, tech companies acknowledge that achieving true quantum advantage requires collective effort, so expect an increase in partnerships within the sector.

Quantum Noise Reduction

In 2023, researchers made several advances in strategies to overcome noise and errors that limit the accuracy and reliability of quantum computers. One approach is IBM's zero noise extrapolation (ZNE) which aims to mitigate these issues, and was key to achieving the aforementioned major step forward in quantum advantage. ZNE intentionally introduces more noise into quantum circuits and then estimates the noiseless result by extrapolating backward. This relies on modeling how noise impacts the quantum computer's outputs. Other approaches aim to protect qubits

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from noise during computations and improve measurements of their states. For example, National Institute of Standards and Technology scientists created a device with a toggle switch to adjust qubit connectivity and isolate them when not needed. This helps reduce environmental noise that disturbs the qubits. Separately, MIT researchers developed a new parametric amplifier that squeezes noise over a broader bandwidth. By redistributing noise, they can amplify the lower-noise variable and get more accurate readouts. Though quantum hardware remains error-prone, these advances reflect encouraging progress toward practical noise reduction.

Quantum Error Detection and Correction

Quantum error detection and correction are essential for the advancement of quantum computing, ensuring accurate computations. 2023 witnessed several significant strides in this area. MIT researchers developed a superconducting qubit architecture using a new type of superconducting qubit called fluxonium, enhancing the accuracy of operations between qubits. This architecture is scalable,

potentially suitable for building large-scale quantum computers. This design achieved over 99.9% accuracy in both two-qubit gates and single-qubit gates. Separately, RIKEN scientists leveraged machine learning for efficient approximate quantum error correction, outperforming other methods. Another team, in a collaboration among Harvard, MIT, and QuEra Computing, reported a significant breakthrough in Nature. Their platform, based on an array of cold, laser-trapped rubidium atoms, each acting as a qubit, demonstrated near-flawless performance of two-qubit entangling gates with extremely low error rates. They achieved the ability to entangle atoms with error rates below 0.5%, a major step forward in quantum error correction. Additionally, Caltech researchers demonstrated a type of quantum eraser, effectively pinpointing and correcting "erasure" errors in quantum computing systems. They developed a system where erroneous atoms fluoresce when hit with a laser, allowing for precise error location and removal. Their method achieved a tenfold improvement in entanglement rates compared to previous

efforts, reaching the highest-ever observed entanglement rate in such systems. Collectively, these advancements represent major steps towards realizing robust, scalable, and accurate quantum computing.

Hybrid Classical-Quantum

As we await the era of full quantum supremacy, hybrid classical-quantum computing has emerged as a practical solution in the interim. Hybrid systems combine the strengths of quantum computers, like running complex simulations or factoring large numbers, with the capabilities of classical computers for tasks like data management and error correction. This allows us to tap into the potential of quantum even with its present limitation. In March 2023, Nvidia announced an important advancement in hybrid computing with the DGX Quantum system, the first GPU-accelerated quantum computer. The DGX Quantum incorporates Quantum Machines' sophisticated quantum control platform OPX together with Nvidia's powerful Grace Hopper Superchip and CUDA Quantum programming model.

This combination enables researchers to run intricate applications that utilize both quantum and classical computing strengths. Key capabilities like quantum error correction, calibration, control, and execution of hybrid algorithms are now viable, ushering in a new era of quantum-accelerated supercomputing.

Quantum Quality Over Quantity

Some quantum computing companies have shifted their focus from chasing qubit count records to building practical systems that can solve real-world problems. For example, IBM's new 133-qubit Heron processor shows an emphasis on qubit quality over raw qubit numbers. Though lower qubit count than previous IBM chips, Heron's modular design may enable scaling to far larger sizes by connecting multiple processors. This "modular" approach could be key to more powerful quantum computers. IBM will connect Heron chips using conventional electronics, disrupting their quantum states. However, IBM's vision is that quantum-compatible links, like fiber optics or microwaves, will enable modular chips to connect into a distributed, scaled

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system—potentially millions of high-quality qubits. Companies like PsiQuantum have similar modular visions.

PsiQuantum, a company using photons as qubits, is nearly done with a modular silicon quantum chip design. According to Chief Scientific Officer Peter Shadbolt, an ultrafast, low-loss optical switch—the last component needed—will mean all features are in place for a scalable quantum chip. PsiQuantum will then connect many chips into a cohesive system at warehouse scale. Announcements from multiple companies point to modular multi-chip quantum systems as a key area of progress to watch in 2024 and beyond. They could signify a path to finally achieving quantum computers with hundreds of high-quality qubits and meaningful computational power.

Quantum Machine Learning

The complexity and enormity of drug design pose significant challenges for traditional computational methods. Due to the countless number of possible molecular candidates, even the most advanced supercomputers

are exhausted. But these types of complex computation problems are where quantum computers shine. A team from the Russian Quantum Center in Skolkovo, Moscow, has demonstrated that quantum computing devices together with machine learning can be used for generative chemistry and drug design. They developed a hybrid architecture that melds quantum computers with deep classical networks, overcoming the complexities inherent in the structural space of potential drug-like molecules. Their compact model successfully generated 2,331 novel chemical structures from a subset of the ChEMBL database of biologically active compounds. This outcome is exciting because it demonstrates the feasibility of using currently available or soon-to-be-released quantum devices for real-world health applications.

The Quantum Internet

The quantum internet is a proposed future network that would allow quantum computers and quantum devices to communicate with each other using quantum information.

A quantum internet could provide virtually unhackable communications since qubits rely on the physical properties of photons, which cannot be intercepted. The laws of quantum mechanics simply do not allow it; any attempt to observe particles in a quantum state will alter the particles and thus destroy any information they transmit. In May 2023, researchers at the University of Innsbruck built the first long-distance quantum repeater node for telecommunication networks transmitting quantum information over 50 km of optical fiber. This is significant because until now, the likelihood of photons being lost over long distances was very high. The researchers showed that with some improvements, their design could transmit over 800 km, enough to connect Innsbruck and Vienna. Separately, Princeton researchers have also made a significant advancement in quantum communication by developing a new type of quantum repeater—key for linking quantum computers over large distances. Unlike classical data, which can travel long distances without interruption, quantum information requires quantum re-

peaters to relay information in segments. The Princeton team's device stands out for its use of infrared light, which is more robust for fiber optic transmission than the visible light used in other designs. They achieved this by embedding a single rare earth ion in a crystal, emitting light at the ideal infrared wavelength, thus eliminating the need for signal conversion.

Open-Source Quantum Software

Quantum computing holds great promise but remains prohibitively expensive for most researchers. Individual hobbyists cannot build quantum computers in their garages; only governments and large companies can afford the capital required. This poses a problem because, like any scientific field, quantum computing would accelerate with more minds contributing. So, researchers are motivated to develop open-source tools for greater collaboration. One example is SuperConga, open-source software to simulate quantum materials. Researchers at Chalmers University in Sweden created SuperConga specifically to understand unconventional superconductors, which have properties that could protect

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quantum information. But because experiments are difficult, expensive, and time-consuming, a lot is unknown about these little-explored superconductors.

That's where a tool like SuperConga comes in. The key is studying quantum properties from the microscopic particle level up to the macroscopic scale. Researchers need tools that work in between, at the mesoscopic level. Open-source software like SuperConga lowers the barrier so more researchers can drive progress in quantum computing. With a collaborative ecosystem, the field can advance more rapidly.

A Developers' Quantum Toolbox

Programming quantum computers presents significant challenges, primarily because they introduce an entirely new computational paradigm. Quantum computations are often described using the quantum circuit model, where algorithms are expressed as a predefined sequence of quantum operations. This structure can make it difficult to implement certain programming concepts common in classical computing, such as flexible routines with conditional logic and loops. Once a quantum circuit is executed and an output is generated, the quantum state collapses upon measurement, marking the end of that specific computation. Horizon Quantum Computing is building a set of programming tools that enable developers to perform flexible computation routines on quantum computers. The approach would allow users to write programs in classical languages that can be compiled on quantum computers, without requiring any knowledge of quantum computing. There is also growing recognition of the need for new "non-standard" quantum programming approaches. Hybrid quantum-classical computing and versatile programming models are increasingly seen as promising paths forward. Companies like Algorithmiq are pursuing these paths by combining quantum computing with classical algorithms specifically for drug discovery.

Quantum-as-a-Service

Owning and maintaining a quantum computer requires substantial financial resources and a high level of technical expertise. To increase accessibility, many companies now offer quantum computing as a cloud-based service, also referred to as quantum-as-a-service or serverless quantum. IBM is one such company providing more accessible quantum computing through its open-source Qiskit software. Qiskit allows classical code to have low-latency access to quantum processors, enabling much faster execution for workloads that leverage quantum hardware through repeated iterations. Everything is provided as encapsulated cloud services, with no capacity planning or lifecycle management required by the user. Microsoft, too, has embraced the quantum-as-a-service model, announcing its Integrated Hybrid feature in Azure Quantum, the company's open software cloud: Researchers can now build applications combining classical and quantum code to run on Quantinuum's quantum computers through Azure Quantum. It's not just companies that are offering quantum in the cloud; China recently launched two quantum cloud platforms to allow public access to the country's quantum computers. One provides access to China's fastest quantum computer, Zuchongzhi 2, and the other access to Quafu, a computer from the Beijing Academy of Quantum Information Sciences. Both will provide researchers and students hands-on access to advance quantum computing research and education.

Quantum Resistant Cryptography

"Q-Day" refers to the threshold when quantum computers can crack traditional internet-securing encryption protocols. This possibility was first predicted in 1994 by Peter Shor of Bell Labs, who published a paper showing quantum algorithms could crack RSA encryption, a system relying on large prime number keys, unsolvable by today's supercomputers but potentially crackable in minutes by quantum computers. This suggests the first entity to create a working quantum computer gains massive hacking capabilities. Acknowledging this, companies like Vodafone have announced partnerships with companies like SandboxAQ to test quantum-safe VPNs, using cryptographic algorithms from the US National Institute of Standards and Technology.

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They're anticipating cyberattackers may already be collecting data for future decryption with quantum computers—a threat known as "Store Now, Decrypt Later"—and testing quantum vulnerability scenarios on smartphones.

Multi-tasking Quantum

Researchers at the University of Sussex and Universal Quantum have achieved a major milestone in quantum computing: successfully demonstrating the direct transfer of quantum bits (qubits) between microchips at remarkable speed and accuracy. Published in Nature, this advancement addresses a key challenge in constructing potent quantum computers to tackle complex problems. The team used a new "UQ Connect" technique involving electric field links to rapidly and precisely transfer qubits between quantum microchip modules. This Lego-like assembly method enables larger, multi-tasking quantum systems. Unlike classical sequential processing, quantum computers can perform calculations simultaneously, leveraging quantum properties like superposition and entanglement. Reliable inter-chip qubit trans-

fers have been a major obstacle, often causing information degradation. However, Sussex's breakthrough achieved 99.999993% accuracy, overcoming this barrier. Collaboration with Rolls-Royce aims to apply enhanced quantum capabilities to develop highly efficient machines. This rapid, precise qubit chip connectivity brings advanced, multi-tasking quantum computers closer to reality. It demonstrates the feasibility of linking multiple quantum microchips to construct vastly more powerful systems and expands possibilities for real-world quantum applications.

Light-based Quantum Technologies

Two recent studies showcase significant progress in efficiently manipulating light and quantum particles to advance quantum technologies. Researchers at the University of Stuttgart enhanced the efficiency of a vital quantum component, surpassing the presumed theoretical limit. By increasing efficiency from 50% to 57.9%, their seemingly small gain enables multiple sequential quantum measurements, boosting long-dis-

tance communication. Separately, University of Waterloo scientists developed an optical system to control individual barium ion qubits with record precision, targeting them just microns apart. Barium ions are gaining popularity in the field of trapped ion quantum computation for their manipulation with visible versus ultraviolet light. This enables the researchers to use commercial available optical technologies. Their new laser focusing method via a glass waveguide establishes a straightforward yet highly precise approach to controlling qubits for computing, communication and more. Together, these advances strengthen quantum foundations while bringing practical, efficient quantum devices closer to reality.

Unlike traditional computers, quantum computers use quantum bits or qubits, which can represent and store information as both 0 and 1 simultaneously thanks to superposition, enabling quantum computers to process complex data and perform calculations at speeds unattainable by classical computers.

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Criminal Caught With Quantum

New York City, 2038—In a groundbreaking revelation, two of New York's premier banks, JPMorgan Chase and Citigroup, have successfully thwarted an advanced cyber intrusion, thanks to their recent implementation of Quantum Key Distribution (QKD). The security breach, which went unnoticed for years, was finally detected and led to the capture of the notorious hacker known as Cipher. Cipher, whose real identity remains confidential, had been intercepting sensitive financial transactions between the two banking giants for several years. The stealthy infiltration managed to bypass all classical encryption measures, leaving the banks unaware of the constant surveillance. However, a recent upgrade to QKD technology changed the game.

With QKD's arrival, the banks initiated a trial run to ensure the efficacy of the system. During a routine transaction, the technology signaled an anomaly in the quantum channel. Kate Garlow, JPMorgan's head of cybersecurity, explains, "When we implemented QKD, we didn't expect to find evidence of a security breach. We realized something was amiss when the qubits' state collapsed during transmission, a clear indication of eavesdropping." Jorrie Norris, Citigroup's chief technology officer, adds, "We knew right away that this wasn't an ordinary attempt. Cipher had been watching us for years, but QKD made his presence known."

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Communal Compute at the Stadium

Carson makes her way to her seat at Arrowhead Stadium. She's a life-long Kansas City Chiefs fan, and she's taking advantage of being on call to catch the game, confident that her boss won't find out.

Not long after she sits down, though, Carson's phone buzzes; it's her boss, urgently requesting her to run a quick test on a model. A pang of panic hits her. She's without her work computer, and the model requires significant processing power to run. However, she has her Steam Deck with her, which allows her to access her work applications and data in the cloud. While the Steam Deck is powerful, it's not enough to run the model efficiently and quickly enough to avoid raising her boss's suspicions.

Then, Carson remembers a recent announcement from her network provider about a new proximity-based compute-sharing feature. This feature allows her device to tap into the spare processing capacity of other nearby devices connected to the same network platform.

Quickly, Carson activates this shared intelligence, making use of the crowd's idle computing power. The model runs smoothly and efficiently on her Steam Deck, something that would normally be impossible given its limitations. She sends off the results to her boss just as the stadium erupts in cheers for the kickoff.

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AI at the Edge

Large language models (LLMs) require massive computing power, often relying on distant, centralized data centers (cloud). However, providers can optimize costs and performance by balancing the cloud with edge computing—processing directly on local devices. While data centers provide the robust computing power needed for training and running massive LLMs, processing directly on user devices at the edge can greatly improve performance. These LLMs can take months to train and run on complex servers costing over $30,000 per GPU, but providers can significantly cut costs by running lightweight versions locally on users' devices. Doing this also reduces latency, improves privacy, lowers data transfer costs, and increases accessibility. For example, Microsoft's Office 365 Co-pilot uses on-device AI to assist users across Windows, Google's Gecko Palm 2 model runs efficiently on mobile, and Meta's LLaMA has a 7B parameter version for edge devices. By combining the power of the cloud with the speed and efficiency of edge computing, vendors can bring the benefits of AI to more users at lower cost.
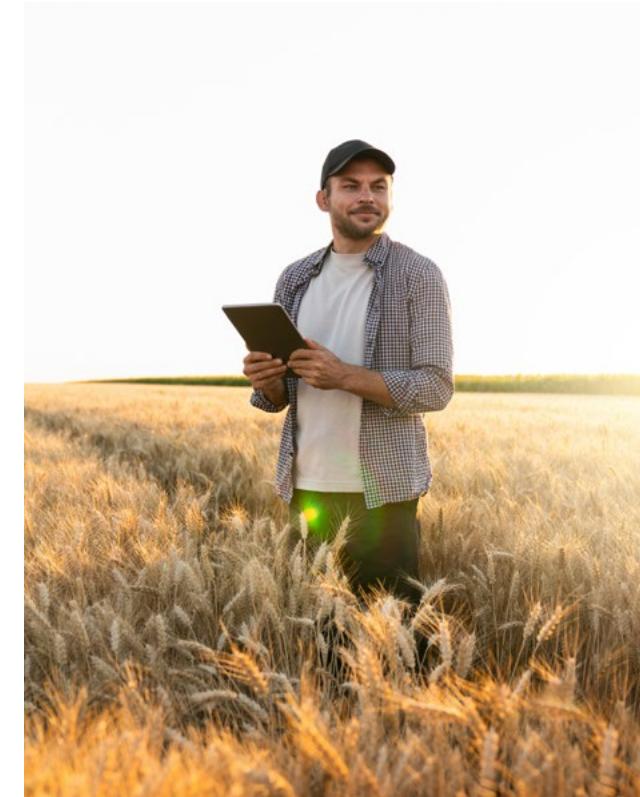
Efficiency Improvements

Researchers from the University of Leicester have made significant strides in addressing the growing demands on mobile telecommunications networks. With an anticipated rise in connected devices, they developed a new technique known as multicarrier-division duplex. This technique focuses on resolving self-interference issues in 5G networks, a crucial factor that affects communication quality and efficiency. By utilizing fast Fourier transform processing, their approach optimizes the assignment of subcarrier sets and the number of access point clusters. In simulations mimicking real-world industrial settings, this technology demonstrated superior performance compared to existing methods, achieving a notable 10% reduction in power consumption. This advancement indicates a significant step towards more energy-efficient and effective telecommunications networks. Simultaneously, researchers at the University of California San Diego have been working on enhancing the utilization of the 5G-and-beyond millimeter wave (mmWave) network. Their research tackles

the challenge of efficiently distributing data across these high-frequency spectra. To address this, they developed a novel antenna system known as a delay phased array. This system divides a single frequency band into multiple usable beams, effectively reducing bandwidth wastage and lag in 5G mmWave systems. Their prototype device decreased lag by 60-150%. Together, these research efforts aim to meet the increasing demands for high-speed, efficient, and reliable wireless communication.

The 6G Cyber-physical Continuum

In 2022, the deployment of 5G technology unfolded globally, albeit at a pace slower than initially projected. Meanwhile, its successor, 6G, is already in the early stages of development, with an expected market launch in the early 2030s. 6G, characterized by its remarkably low latency, is anticipated to facilitate truly immersive experiences. Telecommunications company Ericsson, a frontrunner in 5G and edge technologies, envisions that 6G will enable unimpeded movement within the cyber-physical contin-

AI at the edge allows devices to run large language models locally, enabling smart applications on-the-go without needing constant internet connectivity.

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uum. This continuum represents the interplay between our tangible world—filled with senses, actions, and experiences—and its programmable digital counterpart.

Ericsson's vision of the cyber-physical continuum extends beyond the commonly understood metaverse, where avatars interact within a virtual reality/augmented reality environment. It proposes a tighter integration with reality, enabling the projection of digital entities onto their physical counterparts represented in the digital space. This fusion of realities paves the way for a "merged reality," thereby enriching our actual world. According to Ericsson, 6G will herald an era of a digitized and programmable physical world, interconnected and sustainable. This new age will be bolstered by intelligent machines and the Internet of Senses, providing a synergistic support system for human endeavors.

6G Global Competition

The global 6G race is escalating, with the US, China, and India investing heavily in advancing their telecom capabilities. The

US, acknowledging China's impressive 5G deployment and 6G satellite experiments, is prioritizing 6G to sustain its technological and defense leadership. The country's Special Competitive Studies Project, led by ex-Google CEO Eric Schmidt, has revealed a comprehensive plan promoting policies to reinstate US dominance in 5G and beyond, which includes establishing pervasive, interoperable connectivity and winning the 6G race. This strategy underscores the US' current shortage of major producers of complete telecom solutions.

Meanwhile, China has designated 6G as a pivotal tech priority; a commitment demonstrated by China Telecom's white paper advocating for an intelligent programmable RAN network. China's national 6G coordinating body, IMT-2030, is encouraging innovative tech proposals to create a substantial repository of potential 6G technologies. Simultaneously, India's intention to be a player in the global 6G race was made clear with Prime Minister Narendra Modi's unveiling of the Bharat 6G Vision document, which outlines a plan for 6G deployment by 2030.

First 6G Real-time Wire Transmission

In a major breakthrough for next-generation wireless technology, researchers at the China Aerospace Science and Industry Corporation's Second Institute have achieved the first real-time wireless data transmission using 6G cellular networks. The team successfully transmitted data at an unprecedented rate of 100 gigabits per second on a 10 GHz bandwidth at a frequency of 110 GHz. This marks a significant leap forward from current 5G capabilities by utilizing the higher frequency terahertz range of the electromagnetic spectrum between 100 GHz and 10 THz. Transmitting in the terahertz range enables substantially faster data transfer rates and increased transmission capacity compared to microwave frequencies used in existing cellular networks. Another key innovation demonstrated was the use of orbital angular momentum (OAM) multiplexing for encoding signals. By using OAM, the researchers were able to transmit multiple signals simultaneously on the same frequency, proving this as a more efficient method for exploiting the available spectrum. The

research underscores the potential of 6G to meet the ever-growing data demands of the future through ultra-fast speeds, increased capacity, and spectral efficiency.

Reducing Inference for 6G

To achieve the faster data rates expected with 6G networks, signals will be distributed across an extremely wide frequency spectrum in the millimeter wave and terahertz bands. However, spreading signals so broadly increases the risk of interference between communication channels. To address this challenge, researchers have sought to develop a filter that can protect receivers across the full 6G radio frequency spectrum. For practical widespread deployment, this filter needs to be compact, energy-efficient, multifunctional, and able to be integrated on a chip. To do this, researchers created a simplified photonic architecture for the filter. Unlike previous programmable integrated microwave photonic filters composed of hundreds of repeating units, this simplified design achieves comparable performance with lower loss and complexity. The filter chip therefore has the potential to enhance wire-

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less communication, which would lead to faster internet at a lower cost and with less energy consumption.

Wi-Fi 7

While many only recently updated their networks to Wi-Fi 6 or 6E, the next generation Wi-Fi 7 has already arrived to build on their advancements. With Wi-Fi 7, users can expect a substantial increase in network speeds, a leap made possible by the expansive 6GHz band. This new standard maintains compatibility with older devices, ensuring a seamless transition. As consumers gradually upgrade their gadgets, they'll notice significant improvements in network stability and performance. With the ability to combine links across bands, Wi-Fi 7 routers can dynamically route data based on capacity, reducing congestion.

Wi-Fi 7 promises major benefits for home and office networks straining under the load of more devices and bandwidth-hungry applications. By delivering speeds exceeding 30Gbps, the new standard will help make activities like videoconferencing, gaming, and VR more reliable and responsive. The improved OFDMA encoding allows more simultaneous device connections by avoiding interference. With router manufacturers already supporting Wi-Fi 7, compatible laptops debuted at CES 2023 to take advantage of faster throughput and lower latency when untethered. As the successor to Wi-Fi 6, Wi-Fi 7 brings the robust, high-performance wireless connectivity that modern smart homes and workspaces demand.

The most recent update to the Wi-Fi standard offers the potential for "near-zero" latency, making it ideal for real-time applications such as wireless streaming of virtual reality content.

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The Sisyphus Program: A Physical-Digital Continuum

Albert lost his manufacturing job to automation a year ago. Since then, he's been receiving a similar level of compensation by selling his personal data but he soon falls into a rut, feeling useless without being able to mentally tie his monetary compensation to actual work output.

When he hears of the Sisyphus program, he decides to give it a try. Sisyphus is a pervasive application—it's not an app to download to a phone but rather one you can download to a home. The app assigns daily goals tailored to an individual's interests and tasks around the home, awarding points for completed activities, thereby providing a sense of accomplishment and pride similar to receiving a paycheck for work output.

Sisyphus starts assigning Albert daily goals optimized for his interests. The home hub uses internal sensors to identify things that need to be fixed and locate where he last left his guitar, and external sensors to tell him the ideal time to take his dog for a walk based on the temperature outside. Albert is awarded points for these activities. Even though it isn't real money, he feels the same sense of pride he experienced when receiving a paycheck because he can more clearly tie his physical tasks to rewards.

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BUILT ENVIRONMENT

Future Today
Institute

TABLE OF CONTENTS

TOP HEADLINES

As some cities face the dual challenges of aging infrastructure and urban decay, compounded by sinking, new technologies are emerging to tackle these issues along with other concerns like housing and sustainability.

01

Sensors Are Predicting Structural Failures

Sensors are increasingly relied on to keep tabs on the aging and repair needs of buildings.

02

The Empty Office Crisis Persists

Office conversion and adaptive reuse are turning spaces back into functional assets rather than relics of traditional 9-5, in-person workdays.

03

The Alarming Reality of Urban Areas Rapidly Sinking

Many cities are reporting that, just like Venice, their foundations are eroding. Jakarta, Indonesia, is ranked as the fastest sinking city in the world.

04

Pigmentless Paint Becomes a Sustainable Solution

University of Central Florida's plasmonic paint uses new ways to produce colors that can keep buildings cooler.

05

World's Largest 3D Printed Neighborhood Is Underway

A new property development outside of Austin, Texas, is set to become the world's largest additively made community.

STATE OF PLAY

Focusing on Responsible and Responsive Buildings, Structures, and Construction

As the built environment struggles to deal with a dwindling talent pool and rising costs related to supply chain shortages, built environment professionals are facing their own existential crisis. They're trying to hold onto their relevancy amid heightened interest to adopt artificial intelligence, robotics, and new construction practices that deliver projects faster and more efficiently. They're also unsure what skills will be most in demand for their industry in the future, and are considering how they can bring human-centric behaviors to the forefront in the meantime.

The industry is further looking in the mirror amid an increase in environmental activism and calls for more responsible practices—as it is, the built environment industry is widely known as one of the leading causes of waste and consumption in the world. New practices such as rewilding and deconstruction are gaining prominence and even regulatory backing from regions and municipalities. This shift is building off the focus on fostering health and wellness to create places where people want to spend their time.

New technologies for power generation, infrastructure, and data collection offer ways for projects to last longer, which then raises questions about what that future longevity looks like. Completely connected projects that use sensors, drones, and other tools are providing real-time data that is also being leveraged to generate drawings, models, business strategies, and practices that enable better-informed decisions by both companies and clients. All of these developments highlight a push to challenge outdated practices and move into a new era for this industry.

KEY EVENTS

FEBRUARY 15, 2023

Earthquake-Resistant Tower Completed
In Tokyo, a new supertall skyscraper was specifically designed and built to resist the impacts of earthquakes.

JULY 21, 2023

Self-Healing Metal Discovery
Researchers investigating cracks at a microscopic level observe metal self-healing under a process called cold welding.

OCTOBER 3, 2023

Tallest Timber Building Approved
Developers in Perth get the OK to start working on what will be the world's tallest building using timber construction.

MARCH 31, 2023

India's 3D Printed Bridge
Thanks to a new process, India now has its first 3D printed bridge using indigenous materials.

SEPTEMBER 9, 2023

ICC Code Updates Bring Necessary Changes
Finding building code updates will be easier with the use of QR codes, while waste management also gets more attention.

LIKELY NEAR TERM DEVELOPMENTS

CLIENTS HAVE NEW REQUIREMENTS EXPECTATIONS

Integrated data and the output from models that use that data are becoming more of a requirement, allowing for greater manipulation and understanding in the preconstruction and documentation phases. Clients will continue to want proof that a project will perform financially, and to interact and engage with that data on a more routine basis. More regions and municipalities will also want plans that extend beyond the structure itself, including options for what to do with the materials once the life cycle of the project is complete, as well as plans for how to convert entire blocks or just rooftops into functional spaces. The upfront planning process will become even more important as technology will more clearly show what should be prioritized, such as a road to be fixed or a new sewer system to be installed.

Deconstruction Plans Become Required

Many areas already have deconstruction requirements, aiming to reduce waste heading to a landfill. These types of requirements will likely only continue to increase, which will change permit and construction planning.

Immersive Design Leads to Spatial Relevancy

As the world becomes more immersed in technology, screens and devices are continuing to shrink. This means that spaces will need to accommodate for more immersive experiences in their design.

Built Environment Develops Data Markets

With a vast pool of human-centric data, the built environment is sitting on untapped revenue streams of information that could benefit many business sectors. Past client contracts may prevent this from occurring, but newly developed contracts would allow firms to sell this data.

Cities Organize Themselves

Urban planning and development requires long-term strategy and planning, which can be complicated by sudden societal shifts and needs. AI and digital twins will be able to help accommodate for these shifts, increasing the chances of automated planning directing where developments should take place next.

Jurisdictions and Developers Require Second-Life Designs

Just as deconstruction will likely be regulated, so will adaptive reuse projects that address housing shortages. New mixed-use zoning or urban zoning developments will likely enable this change.

Smart Green Infrastructure Combats Eco-Anxiety

The urgency of climate change could lead to an increase in eco-friendly infrastructure that allows for power sharing and carbon-free transportation. These updates could bring resilience to areas where people worry about being displaced due to climate change.

11 MACRO SOURCES OF DISRUPTION
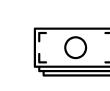
| Technology | Media & Telecom | Demographics | Environment | Government | Public Health | Education | Geopolitics | Infrastructure | Economy | Wealth Distribution |

WHY BUILT ENVIRONMENT TRENDS MATTER TO YOUR ORGANIZATION

Additive Manufacturing

Additive manufacturing will speed up construction, reduce costs and inventory needs, and increase material efficiency. The customization enabled through this process will also change the way designs come to life. This type of manufacturing has the potential to create new opportunities for on-demand and on-site selling.

IoT Data Collection

As cities and spaces collect more data, this information will continue to reveal what should be prioritized and what is unnecessary, enabling real-time management and decision-making. This will also help reduce upfront costs and costs over time as the data will help companies make better decisions.

Predictive Maintenance

Unexpected costs for buildings, bridges, roadways, sewers, factories, and other structures will continue to be a headache for facility managers and city workers. New tools for predicting maintenance will enable better budget planning and help developers estimate yearly upfront costs with greater accuracy.

Smart Urban Planning

For developing regions, planning and development takes massive partnerships and relies heavily on outside expertise. New tools for automating this process could provide cost savings to those regions, which would shift the types of business partnerships they might seek. For established regions, these automated tools will allow for longer planning initiatives but may also be unsettling for residents.

Regenerative Infrastructure

Regenerative and greener infrastructure will ultimately lead to cost savings for businesses, cities, and residents— as well as help address risks due to location and climate change. Investing in this infrastructure will also build bonds to communities and help investors see progress on declared sustainability goals.

Inclusivity

As younger generations consider where they want to live and work, creating places that are more inclusive will ultimately attract these future workers to regions that prioritize this type of design. This can help bring in new talent and prepare companies for new regulations that require greater accessibility and diversity.

OPPORTUNITIES & THREATS

Threats

Scaling new technology and practices will continue to be a hurdle due to a lack of long-term planning.

The need to evolve traditional design and business practices as the industry becomes commoditized is urgent.

Communities will resist the necessity of new technologies due to a lack of exposure and understanding of what they are.

The tech gap in de-prioritized cities and communities will continue to widen.

New data privacy requirements will be a barrier as the industry begins to rely on even more data collection sensors and tools.

Opportunities

Cutting-edge automation will unlock efficiency to combat the talent shortage.

Expanded practices can provide new revenue streams—if the right experts are in place to manage new offerings.

New sources of data can empower clients with insightful, decision-enhancing analytics.

Niche markets offer an opening to prominence in the industry, if innovative services are brought along.

State-of-the-art materials and technology plus time for upskilling encourage dynamic career growth.

INVESTMENTS AND ACTIONS TO CONSIDER

1

Consider investing in creating or finding LLMs specific to the built environment industry. Currently, there is a lack of an industry-specific model that can become an industry standard. The first to market with this development will set the tone for how AI will be used in the future.

2

Returning to more natural processes will require considerable investment in new details, strategic plans, and communications. These investments should be planned out to determine when their impact will be most relevant to clients and when strategic partnerships can be used to leapfrog competitors.

3

Reconstruction and deconstruction will require investment in new equipment and monitoring of regulations. Lobbying for and adapting to regulations that do not completely disrupt the industry, but are still proactive for the environment, could require diverse strategies.

4

Cities will need to create investment strategies that align with chrono-urbanism requirements, meaning more mixed-use site investments and planning will be required. This, along with necessary smart city investments, could tie up budgets for many cities over the next decade.

5

As water scarcity continues, investments in water monitoring will become more crucial. This will allow residents to feel safe, and potentially attract more mobile residents to shore up tax bases within municipalities and regions suffering from people moving away.

6

Additive manufacturing construction practices will continue to grow and scale. Investing in these technologies now will acquaint companies with how these technologies work as they evolve. Consider starting with smaller forms of equipment that facilitate creating pieces and parts that can bolster supply chains.

CENTRAL THEMES

Still Working Toward Automation

Finding the right balance between automation and human intervention and design is a work in progress. Tension comes into play when looking at what automation could mean for rising costs and labor shortages—depending on whether you see it as a boon or a threat. Researchers are studying the use of artificial intelligence in planning, such as in automating the iteration, validation, and selection processes. While other industries are focusing on AI automation throughout the value chain, for the built environment, the focus for automation is mainly on the front and back end of a project or process: This presents opportunities that could be captured and developed.

Data for Decisions

Data collection and modeling will keep increasing, with digital twins expanding what building information modeling can mean for projects and decisions. Besides allowing leaders, officials, developers, and clients to study the effect of their decisions on an overall project, these intelligent models can contain sensors and other devices that collect more data and allow project components to speak for themselves in new ways. But because digital twins require a higher degree of modeling, the quality of the models and their reporting require more accuracy. This data is now becoming a requirement for the front end of projects, even before construction documentation gets underway.

Material Intelligence

Materials are becoming smarter and more capable of self-management, so our understanding of how they work needs to evolve. Self-managing, self-assembling, and self-healing are just a few of the newer attributes becoming more mainstream. Documentation practices are changing as a result, and investments are gaining longevity—buildings could potentially last longer with less maintenance for developers and cities. The development of material intelligence is likely to continue to grow, and so will the need for new staffing positions and updates to performance and code restrictions.

CENTRAL THEMES

Climate Change Responsibility

As more communities deal with extreme weather, cities and companies increasingly want their infrastructure and buildings to be prepared for a crisis. Planning for climate change requires heightened awareness of the materials used and the structure that's created. Developers require more upfront data on how and where materials were manufactured and shipped. The long-term aftereffects need to be modeled to ensure the surrounding area will not be harmed over the life of the project. More mixed-use developments are occurring because of these changes, with amenities being implemented in more condensed, neighborhood-like buildings and shifting what was usually found in urban centers to neighborhoods. Returning processes back to their natural way of functioning is also changing how land is developed and what designs are considered.

New Forms of Monitoring

Aging is a big consideration for what new technology and products can monitor and predict. The wear and tear on existing places, spaces, and infrastructure is a concern especially in areas trying to compete with neighboring regions implementing smart infrastructure. Areas dealing with urban decay or failing infrastructure have tough choices on where to allocate their capital improvement budgets and will expect technology to provide more insight into when these failings could occur. This includes new tools for monitoring resources, especially dwindling natural resources. For smart cities, new advances are allowing for detailed monitoring of residents.

Scaling Disruptions

Ready to upend the built environment industry, additive manufacturing, mass timber construction, modular construction, and regenerative design are all advancing but have yet to scale. This trend can already be seen with new uses for modular construction for mobility, regenerative buildings giving back to their community, the use of additive manufacturing to create more efficient builds and parts, and new possibilities for structure and use types. Watching these indicators to see how they develop and are regulated will provide useful information when these technologies scale to prominence and become more of a practice than a novelty.

ONES TO WATCH

Dr. Mohammad Taha, researcher at University of Melbourne, for researching nano inks to change how buildings use energy.

Othmane Zrikem, chief data officer at A/O Proptech, for backing climate technology startups.

Namratha Kothapalli, principal at Speed-invest, for their backing of industrial technology.

Kaj Casén, CEO at Meyer Floating Solutions, for his work on floating housing.

Andrew Binet, assistant professor at University of British Columbia, for their work on ownership in neighborhoods for community engagement and health.

Luca Staricco, associate professor at Politecnico di Torino, for his work on 5-, 10-, and 15-minute cities.

Rainey Shane, social sustainability director at JLL Americas, for her work on the SEAM certification for social equity.

Hu Tengyun, Zhang Xiaodong, Xie Pengfeil, Li Xuecao, Liu Han, and **Sun Daosheng** of the Beijing Institute of Urban Planning & Design, for their work on automating the analysis of vacant lots within cities.

Dr. Ki-Tae Park, lead researcher at Korea Institute of Civil Engineering and Building Technology, for his work on technologies to predict maintenance needed for aging bridges.

Hiroshi Ishii, associate director at MIT Media Lab, and Ozgun Kilic Afsar, a graduate research assistant at MIT Media Lab, for their research on new fabric fibers that promote healing.

Nathan Daix and **Augustin Monfret,** co-founders at SonarVision, for using 3D sound to help those who are visually impaired to navigate a city.

Georgina McDonald, lead of creative and partnerships at SPACE10, for her collaboration project to use AI to design a flat-pack couch.

Antonin Yuji Maeno and **Kelsea Crawford,** co-founders at Cutwork, for their work on PolyRoom, which allows for Lego-like modular construction.

Pavan Akula, assistant professor of civil engineering at the Oregon State University College of Engineering, for his work on creating new materials for 3D printing from CO_2.

K.V.L. Subramaniam and his research group at the Indian Institute of Technology Hyderbad's Department of Civil Engineering for their work on developing new methods for 3D printing bridges.

Neri Oxman, for fusing design, technology, and biology for Oxman, the company she leads.

IMPORTANT TERMS

Additively made
Products, materials, or items made from 3D printing or additive manufacturing.

BIM (building information modeling)
This digital model is used for creating planning and construction documents. It is similar to a digital twin but typically does not evolve after the project is completed.

Biodiversity
The integration and preservation of various biological life-forms and ecosystems.

Built environment
This encompasses projects and practices within architecture, interior design, civil engineering, MEP engineering, structural engineering, landscape architecture, product design and manufacturing, construction, experiential design, and urban planning.

Circular design
A design practice that focuses on creating products and spaces that, once they reach the end of their life cycle, can be repurposed or reused.

Digital twins
A dynamic digital version of a physical object such as a city, roadway, building, or door, a digital twin uses real-time data to produce reports for the object's performance.

Environmental, social, and corporate governance (ESG)
A framework many companies are using to establish their policies for how they address each category.

Experiential design
This is a design practice for creating interactive and sensory experiences.

Extended reality (XR)
A technology that can augment the physical world through either virtual or augmented reality.

International Code Council (ICC)
The council develops model codes and standards for the built environment and is used by over 50 countries.

Internet of Things (IoT)
Devices that are connected through a network to send and receive data.

Large language models (LLMs)
Used to train AI models, LLMs are trained on vast amounts of text data, enabling them to perform a wide range of language-related tasks.

Mass timber construction
A construction process and design technique that uses large or solid engineered wood products for its structural components.

MEP
An abbreviation for mechanical, electrical, and plumbing services.

Metaverse
The underlying technologies that create a more digitally augmented physical world and reality.

Modular construction
A construction process that uses prefabricated components to create a space, building, or other structure.

NAIOP
The US-based Commercial Real Estate Development Association.

Net zero
Projects that are designed so that their use of energy consumed over a year is balanced out by the renewable energy they produce.

Urban center
Traditionally refers to the central downtown area of a city.

ADAPTIVE URBAN ENVIRONMENTS

CHRONO-URBANISM

WHAT IT IS

Chrono-urbanism refers to municipalities seeking to contain everything residents need on a daily basis within a 5-, 10- or 15- minute walk. This is evolving as urban planning studies are utilizing multiple technologies like AI and data mapping.

HOW IT WORKS

Chrono-urbanism studies the layout of current and future planned amenities within a certain time-based restriction. In Melbourne, a pilot program found that 20 minutes is the farthest people were willing to walk for their daily needs, according to C40 Knowledge. Other cities have experimented with this type of urban planning, including Barcelona's "Superblocks," Bogota's children priority zones, Buenos Aires' car-free zone, Paris' direction to create "capitals" in neighborhoods, and more.

In Barcelona, the city has been implementing Superblocks for the past decade, reclaiming urban areas used by cars for people, retail, and social activities. In 2021, a study found a decrease in both air and noise pollution in these areas, while residents also reported a better sense of safety and higher interactions between neighbors.

Technology is now enabling chrono-urbanism planning for such developments, which increases the efficiency of the planning process. Digital Blue Foam worked on its own LLMs that can propose feasible 15-minute city design ideas, so planners can create neighborhoods that will give other residents a similar experience to the Superblocks. Now, 15-minute cities are evolving into chrono-urbanism, informed by a 2022 study that evaluated denser urban areas with tighter time-based circumferences, like 5-, 10-, and 15-minute neighborhoods.

WHY IT MATTERS

Chrono-urbanism can help improve accessibility and walkability for municipalities. As urban centers struggle to retain residents, a focus on chrono-urbanism can make them more inclusive, by attracting new people and widening the demographic. This type of planning can also enable greater sustainability and change transportation methods—both of which will become increasingly important. Localizing services to neighborhoods within these time-centered areas will offer more niche consumers, giving opportunities to businesses looking to break into markets. As these regions grow and shift, population centers will be fluid, and may result in new geographic centers being prioritized. Planners will face the challenges of determining various necessities while also needing to encourage cultural synching within neighborhoods and regions. But ultimately, by understanding the temporal patterns of a city, developers can make more informed decisions about where and what to build. This can lead to more profitable investments, as developments become better aligned with the times when people are most active in certain areas.

SELF-ORGANIZED PLANNING

WHAT IT IS

Technology is automating planning, site selection, and infrastructure deployment around cities. It can now also be used to suggest where vacant sites can be converted for a new purpose.

HOW IT WORKS

Site selection and verification can be a costly and time-consuming process; before any structure is built, real estate developers have to do a lot of upfront work to analyze both the location and market. As cities integrate more technology, the organization and development of neighborhoods, streets, and regions are becoming self-automated.

Now, AI is providing ways to reduce much of the lift in urban planning and development. Software company Deepblocks has released tools for developers and investors to help pick the best site for their projects, including information on zoning and ways to test build through a virtual platform. It also allows for exports of reports based on its analysis. Other companies are looking to take that automation even further. A recently filed patent claims to use AI modeling of a city for automatic site selection based on a set of criteria, to help cities understand how they can utilize underutilized areas. Another patent claims that it can use data to assess vacant areas in a city to see if they are suitable for residential use. With housing shortages around the world, such developments could help cities more efficiently plan.

WHY IT MATTERS

Zoning has been a barrier for many cities as they look to provide infrastructure and amenities to both attract new residents and support existing ones. This technology and planning methodology could help accomplish both goals—aiding both cities looking to address urban decay and developers looking to maximize their investments. Underdeveloped areas or rural regions could identify which investments could help them be more stable or leapfrog a neighbor. More established cities and locations could achieve more resiliency. Some of these new capabilities will shift stakeholder integration and interactions, as residents will still want a say in how their cities are planned, but greater localized data could help provide better insights that reflect the communities' preferences. For businesses, this technology could either end up enabling or disrupting the area around them. If the tools identify that an area is better off zoned for a different function, that could either disrupt the location or bring new customers. And as office spaces are left vacant in cities around the world, automation could help decide how to best replace them.

1ST YEAR ON THE LIST

REWILDING

WHAT IT IS

Urban planners, designers, engineers, and architects are using nature-inspired interventions to restore natural processes and environments in cities. Besides being good for the ecosystem, these enhancements are increasingly in demand by consumers.

HOW IT WORKS

Since the COVID-19 pandemic, the concept of rewilding has gained renewed attention and importance. As lockdowns and restrictions prompted people to reconnect with nature and seek outdoor spaces, there has been a growing recognition of the mental and physical health benefits of green spaces and natural environments. Rewilding efforts, which emphasize restoring and preserving ecosystems, are seen as a way to address some of the planet's inherent environmental challenges, and to build more resilient and sustainable communities.

Cities globally have been incorporating some of these concepts into their urban landscape. In Singapore, towering, artificial "supertrees" serve both aesthetic and ecological functions. These structures are covered in a variety of plants, and the vertical gardens create microhabitats for insects and birds, enhancing local flora biodiversity. The vertical gardens and elevated positions of the supertrees also attract birds, providing roosting sites and potential nesting areas.

Elsewhere, startups are focusing on increasing and enhancing trees. Living Carbon is experimenting with genetically modified trees designed to capture more carbon and absorb greater quantities of heavy metals from the soil than their natural counterparts. And GoPlant.me is leveraging the principles of crowdsourcing to encourage financial support and volunteerism for urban tree planting initiatives.

WHY IT MATTERS

Increased efforts in rewilding is a direct aftereffect of the pandemic that will continue to grow as people prioritize being outside and look to nature to help address mental health challenges. This trend could benefit people and companies in multiple ways, such as by reducing long-term costs like air purification and lowering water use. Restored ecosystems can also act as a natural barrier that developing cities and economies could look to use for protection from climate change effects. Interest in their use will affect urban planning and structural engineering of areas within cities where people want to spend their time.

Companies that prioritize nature may also want to capitalize on this demand by encouraging similar rewilding efforts in the areas they inhabit. Eventually, we could see sponsorships for rewilded areas crop up just as we see parks and roads sponsored by groups wanting to make a statement. But the type of rewilding that's right for both companies and geographic areas should be entertained on a case-by-case-basis because each area will have different needs. As leaders work to prioritize which needs should be met first, expect some tension among residents, developers, and local officials.

REGENERATIVE PRACTICES

ADAPTIVE REUSE AND DECONSTRUCTION

WHAT IT IS

As urban decay threatens many cities, developers and practitioners are giving new life to often-abandoned buildings and areas—converting them into livable and workable areas and spaces.

HOW IT WORKS

Repurposing existing buildings, a sustainable practice, reduces construction waste by up to 40% and cuts the carbon emissions associated with new construction and building material production. Increasing interest in reuse can be found around the world: from the AMP Centre in Sydney, which was one of the first upcycled buildings; to a Dutch engineer's efforts to recycle and reuse all materials in a 14-story office tower; to decommissioned wind turbine blades in Ireland finding new life as footbridges. Such projects could be aided by studies using AI to analyze what is inside a building or structure to know what those materials could be used for in the future.

Beyond AI, other technologies are supporting this effort—specifically sensors and digital twins. These tools are being used to make real-time adjustments as these buildings grow or change, and can also be helpful in maintaining structural integrity, and for knowing where to place additional support. As municipalities are frequently starting to require new developments to have a deconstruction plan, these models could be helpful in the long run.

Adapting interior spaces can also help give buildings a second life. One compelling option for abandoned office buildings is vertical farming. Another is converting offices to other uses: A study by NAIOP has identified medical offices and labs as promising candidates for office conversions, as they have less remote work potential. Several firms are using AI to model out which of these conversions would meet economic and infrastructure constraints. This shift, if it continues, will impact the design of building systems to allow for greater flexibility.

WHY IT MATTERS

Second-life projects can help reinvigorate areas of urban decay—and could also become a major factor to plan for and consider on the front end of a project. This would shift the design process to include planning for both today's and tomorrow's space, which could ultimately lead to a new service offering. It could also mean continual projects that require a partner or project manager dedicated to them for life, beyond facilities personnel.

With global office vacancy rates increasing and as remote work becomes the norm, office vacancies are expected to keep growing, leaving an increasing number of empty office spaces. Converting these vacant offices serves a dual purpose: It addresses the vacancy issue and tackles shortages for other uses including housing. At the same time, it also promotes upcycling and reduces construction waste while cutting construction costs and time. Remodeling can be a cost savings mechanism until items are uncovered that were not originally planned for. With new forms of models and AI, these hurdles could become things of the past.

METAMATERIALS

WHAT IT IS

Emerging materials are on the horizon that are notable for their responsive and programmable nature, along with capabilities that enable greater sustainability and self-repair.

HOW IT WORKS

Metamaterials are smart materials that are enabled with various technologies; they can self-heal, self-assemble, change color, become lighter, or regulate temperature. Stimuli-responsive materials, such as shape memory polymers, are flexible sheets that can continuously change shape under external forces like electromagnetic or thermomechanical stimuli, with the ability to return to their original form. These metamaterials promise to create adaptable structures that respond to their environment, such as self-healing concrete for autonomous repairs and smart windows and building facades that adjust to weather conditions, enhancing energy efficiency.

Researchers have contributed much to these new types of materials lately. Researchers from Boston University have created a new kind of material that blocks sound while allowing for airflow, which could transform building facades in urban and noisy areas. Researchers at the University of Central Florida have developed a new textile that changes color and appearance on demand. And 3D printing and additive manufacturing continue to offer many inroads for metamaterials, including a breakthrough from MIT researchers to 3D print materials that can sense and react to environmental changes.

Additive manufacturing has even built an entire house: The BioHome3D, constructed by the University of Maine, is a 3D printed house that uses scrap lumber, sawdust, and construction debris, combined with biopolymers sourced from plants, animals, bacteria, and fungi to create 3D printed wood. Taking innovation further, 4D printing enables 3D printed smart materials to respond to external stimuli by expanding, contracting, bending, and more. These materials find applications in self-assembling furniture and regenerative systems for infrastructure, like self-repairing piping systems and bridges.

WHY IT MATTERS

Using a single material and a single 3D printing process, this technology has the potential to transform the construction industry by enabling structures that adapt to changing conditions.

The longevity of built elements will become even more important of a consideration as buildings can potentially have multiple—and longer—lives. With new, more responsive materials, even stagnant elements and furnishings can take on a second life, which gives a space more functionality and use. These metamaterials will also change the performance standards for roadways and other essential infrastructure, and can be used to protect structures that provide water and other necessary resources. Developing and integrating more metamaterials should be a priority, especially for regions that lack stability, as they'll help protect against extreme conditions and allow infrastructure to maintain itself. This could be a cost saving for many areas that currently lack manpower during construction and inclement weather.

Moreover, as more people move to urban environments and growth continues, noise is increasingly a factor. As acoustic comfort becomes more elusive, metamaterials can play a key role by changing the comfort rating of spaces based on unique stimuli. While new products are manufactured that include metamaterials, the price point will initially increase. But the enhancements the technology brings to these spaces will be very valuable going forward.

RESILIENT DESIGN

WHAT IT IS

New practices and technologies are helping us plan for future climate change and crises. New spaces for safety, respite, and resiliency are also being created to promote better health and wellness.

HOW IT WORKS

Threats to a region often prompt new strategies for the built environment. Flood-prone areas like New Orleans and Maasbommel in the Netherlands are responding by constructing amphibious homes with buoyant foundations, allowing them to float during floods while maintaining sewer and utility connections through flexible piping. Dutch company MVRDV's Sea Level Rise Catalogue explores other similar ideas, such as floating habitat islands, adaptive structures, and mixed-use high-rises on stilts. Inland developments are addressing water surges with permeable ground coverings and rainwater buffers.

The devastating impact of earthquakes in places like Turkey, Syria, and recently Morocco underscores the importance of anti-seismic construction methods. Buildings are already using flexible foundations and shock absorbers to withstand earthquakes, but so called seismic invisibility cloaks, which use deflectors to protect buildings, making them appear "invisible" to seismic forces, offer new avenues. And where cities are sinking, there's a need for new resilient solutions like artificial recharge and deep soil mixing, requiring careful planning and investment. Scientists are also studying lightweight building materials and foundations to reduce the risk of subsidence.

Resilient design also encompasses creating spaces for respite. Many workplaces are piloting emotion-sensing technology to understand the mental state of their employees, and finding ways to create places for them to decompress—a field that researchers are also studying in educational spaces. A new patent for furniture looks to use sensors that can tell users when they are stressed and should take a break.

WHY IT MATTERS

Given the recent pandemic and ongoing climate change, providing safety and security in structures is top of mind. New forms of resiliency, for both the design and construction of buildings, will be expected to address the potential effects of war, severe storms, wildfires, droughts, and rising sea levels. Managing and analyzing the weaknesses in a region will provide actionable recommendations and strategies that can combat these future issues.

In addition, resilient design can lead to significant cost savings by reducing the damage and economic disruptions caused by disasters. By investing in resilient infrastructure and buildings, communities and businesses can avoid or minimize costly repairs and downtime following a disaster. This stability is crucial for economic growth and investor confidence.

Eventually, public projects could increasingly mandate safety of spaces as area residents require more stability. And with the growing focus on mental health, resilient spaces that create areas to de-stress could become a basic infrastructure requirement—as essential as electricity and water are today. This shift could change building codes and planning, and be helpful in developing areas.

ADDRESSING HOUSING SHORTAGES

WHAT IT IS

With rising homelessness and housing shortages around the globe, cities and companies are creating new forms of housing.

HOW IT WORKS

Homeownership costs are soaring around the globe, and there's not enough housing to meet demand. A Moody's Analytics study found the US is grappling with its lowest housing availability in 30 years. In many countries, housing costs are outpacing income growth, resulting in a severe shortage of affordable options. By 2030, the World Bank predicts that 3 billion people will require new access to adequate housing.

To facilitate new housing construction, cities are exploring rezoning or "upzoning" policies. Japan's flexible zoning and incentives have increased affordable housing through effective supply management. Vienna's social housing model strives to offer quality, affordable homes to all residents; over 60% of its population are in municipally-supported apartments, reducing inequality and promoting social integration.

Innovative data mining is also crucial for new urban planning. Yeme Architects' Community Data Platform helps identify deficiencies in British neighborhoods, information developers can use for deciding whether more schools, shops, or green spaces are needed. MySidewalk, a comprehensive community data library, reveals insights from various data sets, including the US Census and Centers for Disease Control and Prevention to address issues like healthy food access and income inequality, guiding targeted solutions for land development.

Supply chain disruptions and higher labor costs exacerbate the housing affordability problem. A possible solution is what ICON and 14Trees are doing by leading 3D home printing construction technologies, potentially paving ways to reduce costs and emissions.

WHY IT MATTERS

Housing conversions will be a prime focus in the built environment for the next several years. Attainable housing—residential units that are affordable for a wide range of people, especially those with middle-income levels—will also help address social issues. But as civil engineers continue to be tapped to study what could be developed, these types of data mining platforms become more relevant. More adaptable and responsive construction practices and studies are needed, and businesses and companies can help them scale by educating stakeholders in their region and providing case studies to try new forms of implementation. As investors and banks look to place their capital with more responsible companies, those that focus on solutions will be seen as places for goodwill investments. Such funding will bring stability to areas that have seen exponential growth of people experiencing homelessness, or are trying to develop strategies for residents becoming unhoused due to unforeseen conditions. Adequate housing is a foundation for stable employment and economic participation. When people have secure and affordable homes, they are more likely to engage effectively in the workforce—and contribute to overall economic growth and stability.

REGENERATIVE DESIGN

WHAT IT IS

Comprising sustainable and circular design, regenerative design includes spaces, structures, products, real estate practices, and places that are working to give back to the community they sit within and benefit the environment.

HOW IT WORKS

Companies are exploring alternatives to traditional materials that are more sustainable than their counterparts. The K-Briq, created by UK-based startup Kenoteq, is an eco-friendly brick made from 90% construction waste; it matches the appearance and weight of regular bricks but emits just 10% of the carbon and provides improved insulation. Berlin startup Made of Air developed an organic waste-based, carbon-negative bioplastic, storing the equivalent of about two tons of carbon dioxide for every ton of plastic. The bioplastic can be used in building facades, furniture, interiors, transport, and urban infrastructure, sequestering carbon dioxide and aiding in climate change mitigation.

Plantd's proprietary technology transforms rapidly growing perennial grass into carbon-negative structural panels for walls and roofs materials that are stronger and more moisture resistant than competitive products. Developed by MIT chemical engineers, 2DPA-1 is a self-assembling, lightweight polymer that's stronger than steel, offering versatile applications for building materials and structures. Norwegian startup Carbon Crusher repairs roads with recycled asphalt and a plant-based adhesive, which is faster, cost-effective, and carbon-sequestering.

Dutch startup Energy Floors utilizes kinetic harvesting, or energy scavenging, to capture energy from mechanical motion, like foot traffic, converting it into electricity for diverse indoor and outdoor applications. Researchers are also exploring new types of furniture that use algae that can produce energy through a grow light at night.

WHY IT MATTERS

Regenerative design goes beyond reducing harm to actively improving the environment. This approach aligns with growing consumer and stakeholder expectations for companies to be not just environmentally neutral but positively impactful. The built environment is becoming more than just what it can house: New spaces, structures, products, and buildings are becoming more responsible to the community where they reside. That benefits everyone: Companies that embrace regenerative design often lead in innovation, and by adopting regenerative practices, they can ensure the long-term availability of the resources they rely on. This approach also reduces dependency on external and potentially unstable sources, mitigating risks associated with resource scarcity and environmental degradation.

As more regions push for carbon sequestration requirements and energy resilience, they will start to prioritize these products and materials that give back as well. They can start with methods that offer respect on a cultural level and do not have to become homogenized. Tax incentives will surely become one path forward to accelerate this practice, which can help with further research and development within the built environment industry.

SCENARIOS

Amphibious Cities

The gentle sound of water moving has become quite common in Singapore, Helsinki, Jakarta, Miami, and Sydney in 2050, and it's not because its residents are relaxing by the water—rather, water is rising and falling over their homes. Embracing the fact that climate change was unavoidable, these cities were some of the first to implement mixed-use amphibious areas, ultimately leading to completely amphibious cities.

These areas started out as regular neighborhoods but were built using modular components that, as the waters rose, allowed portions of buildings to be submerged without needing to be relocated. In fact, most of the buoyancy comes from the walking spaces under the buildings, which started off as crawl spaces and became an underground tunnel system connecting the amphibious sectors. Above the water, kinetic harvesting wave generators power the areas and have become their own form of public art. Most residents have porches on top of their homes now, so when they venture out for fresh air, they can sit and take in the expansive oceanic view. It works out well for everyone—except some local governments. Many of these amphibious cities face property tax debates with local authorities, seeing as there is now less land or property to tax.

AUGMENTED PRACTICES

1ST YEAR ON THE LIST

SENSORIAL ELEMENTS

WHAT IT IS

Technology is allowing for more immersive experiences and design within the built environment. This includes 3D billboards and other types of digital signage and art.

HOW IT WORKS

Cities like San Diego are experimenting with using 3D billboards and holographic displays to create more visual immersion on sidewalks, retail fronts, and around the city. Individual companies are exploring their options too: brands like Nike and Coach have utilized massive 3D billboards for promotional campaigns in Tokyo and London, and McDonald's used a weather-responsive billboard in the UK for personalized ads.

Artist Refik Anadol is taking this visual, sensorial immersion to another level. He gained fame for using AI in a Museum of Modern Art installation that projected shapeshifting images from the New York museum's vast art collection onto a 24-foot screen. This kind of transition to increasingly kinetic places and spaces is also seen in architecture, where building parts can move without compromising integrity, as they respond to changing human and environmental conditions. The Al-Bahr towers in Abu Dhabi is an example: The buildings have a protective skin of 2,000 glass elements that automatically adjust based on sunlight, offering sustainability benefits as well.

A recent sensory exhibit in Australia looks to move past the visual into touch and play, highlighting ways spaces can be more inclusive for those who are a part of the neurodivergent community. Many retail centers are also looking to infill their vacant spaces with these multi-sensory experiences that use interactive screens to display art and color. Recent displays at the retail show NRF had Samsung displays where you could hear coffee being poured and smell donuts.

WHY IT MATTERS

Visual engagement in the built environment can have the same effect as it does on social media: It prolongs the retention of the memory of that moment, which could help boost desire to return to those places. As many are looking for ways to draw employees, visitors, and residents back into the built environment, these types of immersive experiences can provide an answer.

But there are many other benefits as well. Shared, immersive experiences form social cohesion, and offer branding and cultural engagement that extends beyond traditional community events. They can be bolstered through shared data, which offer ways to curate the content based on who is in the room, which can make these experiences even more meaningful. As wearable technology scales, and users opt in to share their data, this new information provides fodder for community content and preferences.

On the flip side, regulation for visual safety and viewers' data privacy needs to be considered. People passing through public spaces should be made aware if their presence and their data is being used to generate the art, and the art should be representative of all as well.

AUTOMATED DESIGN

WHAT IT IS

AI integration is increasingly prevalent, from automating the design practice and tools, enhancing iterations of drawings, and generating specifications and purchase orders to synthesizing customer insights and enabling decisions on sustainable implementation processes for construction and manufacturing.

HOW IT WORKS

From optimizing traffic planning to ensuring efficient code checking for building permits, city officials and developers are harnessing AI to automate the ways urban spaces can be smarter and more sustainable. They're also using AI to automate understanding of future damage and aging infrastructure. The Korea Institute of Civil Engineering and Building Technology has created D.N.A. (Data, Network, and AI) technologies for forecasting bridge wear and aging, to facilitate proactive and possibly automated upkeep. In a similar vein, data science company Concrete.ai's system allows for the automation and optimization of concrete mixes, with a specific focus on reducing carbon emissions.

AI is also being used to accelerate and improve the construction life cycle. It can automate deliveries and source materials more efficiently, which helps with construction execution planning and updating of construction sequences. Software company IFS offers planning and scheduling optimization products using AI to ensure real-time construction schedule optimization and on-time project completion, while Hypar automates designs by providing a cloud-based platform for integrating predesigned systems into projects.

AI's impact on automating design can also be seen in other ways. AI tools like Maket.ai and Archi.ai are helping to automate plans and design ideas. WINT, or Water Intelligence, is combining AI and IoT to manage water flow and promptly detect anomalies, enhancing water conservation in construction. And two Florida Tech researchers—Hamidreza Najafi and Benjamin Kubwimana—have published a paper proposing a new method for optimizing building energy models (BEMs) using Python EnergyPlus for energy optimization, which would be of benefit to MEP engineers.

WHY IT MATTERS

Automation is already part of urban planning and development, which means that it will increasingly play a larger role in other steps of the process, from design to construction. Already, automating multiple parts of the design process and overall project is becoming more normalized. For companies and industry affiliates, they should expect some portion of their process to be automated soon, if it hasn't been already. The new tools increase efficiency and actually do not stifle creativity: They let built environment professionals see multiple iterations they may not have considered.

When partnered with augmented forms of construction, automation can help scale built environment projects to grow faster, provided that the funding is in place. Clients will ultimately need to provide more data for these types of projects, and the practitioners will need to understand and iterate through the process faster. These changes ultimately require more reliance on technology—not necessarily leading to a reduction in staff but an increase in augmentation practices. This will push traditional design process thinking, something that the entire built environment could take a moment to consider.

1ST YEAR ON THE LIST

METAVERSE ENABLING

WHAT IT IS

While the metaverse is still up in the air—literally and figuratively—many architects and designers are exploring the possibilities of what they can create within it and figuring out how to enable collaboration and accessibility.

HOW IT WORKS

Metaversal technologies include any technology that augments the physical world, and collaboration is one of the main ways many companies are looking to harness the metaverse for the built environment and design process. Some are using virtual reality (VR) for immersive design experiences, while others are experimenting with using augmented reality (AR) to overlay digital information onto the physical world, aiding architects, engineers, and designers in 3D visualization. The RAD Lab at the University of Miami is using mixed reality to offer immersive experiences for its architecture students and enable innovative design collaborations in the metaverse. In the commercial world, Hyve-3D is integrating virtual reality and holographic displays, enabling user interaction with the full project for review and collaboration without a headset.

In 2021, the metaverse's top benchmark was enabling users to overcome real-life obstacles, including disabilities, allowing them to experience places and spaces that they previously could not. That main purpose now extends to others, such as, letting art lovers experience museum exhibitions via AR and VR from afar. Cities are also using the metaverse to enable safety and creativity. Tuvalu aims to become the first digital nation by re-creating itself in the metaverse to safeguard its culture and society amid ongoing threats from rising sea levels and climate change. And Zaha Hadid Architects created "Liberland Metaverse," a virtual unrecognized libertarian state featuring the firm's signature architectural style marked by curves and rounded corners.

WHY IT MATTERS

Use of the metaverse for the built environment is not for living but for experiencing elevated physical interactions. Virtual tourism, already in progress, can be augmented through this technology, with cities, sites, and other experiences being built in the metaverse. For cities looking to attract new residents, they could offer pre-experience city living before a family moves to a new home. For developers, this try-before-you-buy experience in the metaverse will become more important as new properties compete with one another, and the higher the fidelity, the more likely it will resonate with potential tenants. This will also require firms to continue to expand their BIM models with more realistic modeling, which could create larger file sizes and extend the project timeline. Firms could look for ways that other technologies like AI could assist in preventing these complications, or work to reuse components already in the metaverse to their advantage. As public projects go before communities and other decision-makers, digital twins in the metaverse could become a requirement for approval and voting. For the industry itself, metaversal technology offers education opportunities and a more extensive global reach that can help firms achieve their upskilling and diversity goals.

1ST YEAR ON THE LIST

INCLUSIVE DESIGN

WHAT IT IS

Inclusiveness has become a top goal in this industry, and meeting the minimum requirements is no longer palatable. Using technology to address disabilities includes using more participatory design to include the community as part of the design process.

HOW IT WORKS

Enhancing accessibility in public spaces involves working to understand and accommodate diverse neurological and physiological conditions. It can also entail designing public spaces to enable greater mobility and creating novel apps like South Korea's "Dagachi Naranhi" and France's SonarVision to help visually impaired residents navigate their spaces.

Aging is included here. The World Health Organization has released guidelines for age-friendly cities, covering key domains like housing, transportation, and social inclusion; this in turn is driving civil engineers to enhance accessibility with wider sidewalks, ramps, elevators, and improved senior transportation. Brunel University London, in collaboration with Meta and the University of Cambridge, is researching ways to enhance the metaverse's accessibility for disabled and older individuals.

The 2021 Built Environment Social Equity Survey, conducted in collaboration with over two dozen organizations, found that 65% of employees consider increasing racial and gender diversity in the built environment—and within its leadership—important, reflecting a growing emphasis on an inclusive environment's potential to spur innovation and new solutions. The survey further highlights efforts to boost diversity in the built environment, such as youth education. An example is a pilot project in Riga that uses a game environment for local exploration and architectural awareness for kids to learn about the industry.

WHY IT MATTERS

As cities look to prevent urban decay, providing greater accessibility will increase resident satisfaction and use of spaces. For now, most of the technologies are app-based, but greater accessibility would be achieved without the need for an app. Updates could also lead to the redesign of codes and governing statutes that impact how places and spaces are laid out and designed. In an aging world, older demographics will only continue to push for this type of inclusivity, which can impact the products created to be incorporated into spaces and the infrastructure needed to support those products. More inclusive living centers will become more attractive as the aging population continues to grow, which will force developers to consider new unit types, new forms of retail spaces, and new places of care. At a time when mobility is increasing, inclusivity will need to be rethought along roadways, terminals, and lodging locations.

REAL-TIME DATA COLLECTION FOR DECISION-MAKING AND PLANNING

WHAT IT IS

Data collection through sensors and other platforms is now being used for cost estimation, to understand use and behavior patterns, and to make more informed real estate and built environment decisions.

HOW IT WORKS

Due to the pandemic, companies are increasingly adopting occupancy sensor technologies—including passive infrared and ultrasonic and utilization tools to inform space planning and cleaning, as well as to enhance workplace safety and experience. JLL offers a tech service using data analytics for insight-driven real estate decisions, improving areas like energy efficiency and tenant satisfaction. Digital models and other tools are enabling real-time decisions, but these require built-in sensors and other visualization tools to provide the data to model. Gensler's Graph product suite is an example: Its spatial analytics toolkit analyzes and visualizes data from various sources to provide insights for design and space planning.

This data collection and modeling applies to urban planning as well. Rotterdam, Netherlands-based MVRDV has developed RoofScape, a tool using the growing ecosystem of urban municipal data to suggest concrete use cases for underutilized rooftops. For civil engineering, UK water utility company Anglian Water offers a real-time mapping system, which utilizes geospatial technology to prioritize where work is needed. In the system's first six months of operation, it reduced blockages by over 51%, cleaned 112 kilometers of sewers, and removed 8 tons of debris.

Parking is one area heavily invested in data capturing and modeling. Visionful, a US startup, provides cloud-based predictive analytics for parking and also includes a mapped database for faster crime response. France-based Mytraffic uses advanced analytics to provide location insights such as space utilization and traffic management, real estate portfolio performance, and potential locations of business expansions.

WHY IT MATTERS

Data has always mattered, but it has taken on an increased importance. Now, collecting data can lead to better-informed decisions and provide a way to model potential actions before financially committing to plans. But collecting data the right way also matters. Understanding sensor technology will become a critical factor for companies in the built environment industry, along with properly integrating them into projects. Developers and retailers can use sensor technology to implement better amenities and direct targeted use and interactions within their space, and also in preparing for aging infrastructure. This type of preparedness could also help allocate resources during times of crisis or climate change shifts, meaning cities can and should use this type of data collection and plan now to prepare for the future. When people and products are enabled to contribute their data for planning purposes, healthier spaces and products can result. Firms should prepare for more sensor integration and data analyzation on both the front and back end of projects going forward.

SCENARIOS

Instant Permitting

Getting building permits used to take weeks if not months. But now, thanks to automated design and real-time optimization, they can take minutes—that is, if the residents approve and the digital model says it's ready to be built. The shift in permitting was partially due to the increased use of registered digital BIM models, which went to the city as soon as they were started, allowing cities to weigh in on potential code issues ahead of time. This optimization led to more of a collective dialogue between firms, designers, clients, and cities; it's been especially helpful when cities needed to build their own projects, as the models can factor in when construction teams might have downtime due to the permits submitted. Looking to ensure residents' satisfaction, cities have also implemented digital town halls where the digital twins of the potential projects are displayed and voted on by residents. Then, residents feel they are part of the process, and will weigh in on the public infrastructure needed. City inspections now include deconstruction plans, changing demolition permits, which are actually the permits that are hardest to obtain.

SMART CITY IMPLEMENTATIONS

SMART BUILDINGS

WHAT IT IS

The buildings we occupy are becoming further automated as smart technology is incorporated. Smart buildings, integrating advanced technologies and automation for enhanced efficiency and user experience, are emerging as a transformative trend in the built environment sector.

HOW IT WORKS

Building automation continues to give operators greater control over smart building systems. Companies like ABB are selling systems that offer control over HVAC and building energy management; they've brought a range of scalable automation and energy control to the United Arab Emirates, with a plan to continue to deploy its offerings in other places over the next three years. Facilio also expanded into the Australian market, deploying its AI SaaS platform to help with monitoring energy efficiency and fault detection and diagnosis.

Platforms like nClarity offer 24/7 real-time monitoring, using cloud-based analytics to look for anomalies and performance degradation, as well as finding ways to mitigate issues. Typically these systems have been cost affordable only for large-scale buildings, but Siemens debuted a new hub that would allow for its IoT-based system to work with small buildings and even office campuses. ProSentry and Senet's new partnership will offer smart building monitoring for everything from gas leaks to mouse traps.

These smart building management systems are also looking to manage space. Tenantcube helps landlords manage their properties by helping them automate listing and renting. Platforms like the one offered by ApartX also increase automation by using biometrics to automate operations and Smart Residence's app that allows residents to control and reserve amenities in the building. A continued focus on bringing workers back to the office has spurred an increase in technology use for visual and auditory privacy and lighting—including bulbs that help circadian rhythms and other technologies that can automatically detect Covid's presence by smell.

WHY IT MATTERS

Building and space automation continues to focus on efficient systems. As new regulations are handed down, the presence of these systems could separate legacy buildings from newer ones—if more efficient buildings are prioritized, urban decay could fester should those buildings not occupy space in downtown areas. Emerging economies and regional cities could capitalize on this to bypass their neighbors if they have the needed infrastructure in place. For economic stimulation, the development and retrofitting of smart buildings drive growth by creating jobs and stimulating demand for new technologies and services.

In addition, smart buildings generate valuable data that can be used to enhance building management, user experience, and inform future development. Landlords and developers should continue to prioritize these types of buildings, as this type of automation will allow them to tightly manage space occupation, which is a growing concern. It could be useful for future lease and tenant negotiations as well, as they can predict the performance of their future spaces. This could also help tenants, by giving them the very granular data they expect, including the performance of their space when compared to other units in the building and their area.

SMART HOME AUTOMATION AND MONITORING

WHAT IT IS

Homes are continuing to become more helpful and personalized through smart technology.

HOW IT WORKS

Recently, smart homes and apartments have seen an influx of newly connected and automated integrations. The open source interoperability standard Matter became a major focus toward the end of 2023 and continued in 2024. It would allow for in-home devices to control multiple connected components. Other smart home technologies include auto-arming alarms, ovens that allow for livestreamed cooking, sensors that can have fans track your face, heaters that learn to optimize energy consumption, and Kohler's Stillness bath, which uses light and fog to create a soothing environment. Kohler also launched its voice-controlled bidet that has a self-cleaning mode. Lighting controls continue to improve with Phillips' Hue E14 bulb—which includes over a million shades of programmable white light to choose from—and Nano-leaf's Sense+ Controls, which learn when to turn off lights based on a person's daily activity. This dovetails into a continuing trend in smart homes: monitoring for safety. Elsi's Smart Floor can track if a person has fallen, and MIT created a monitor that can track how Parkinson's disease has progressed based on the afflicted person's gait.

In many homes and apartments, noise is a top complaint; it may soon be addressed by a new plasma-based silencing technology. Another chief challenge is space: in response, Ori, a provider of multifunctional, robotic-power spaces, has launched a pocket office that can expand and collapse to turn one space into two. And to increase security, researchers have filed a new patent to use doorbell cameras and other CCTV cameras to track and predict criminal activity in an area. This includes Lockly's Visage, a smart lock that can store 100 face profiles to allow entry to a home.

WHY IT MATTERS

Most people spend a lot of their time at home, and in-home smart technology continues to change the way people interact with their environment. As the world's population gets older, integrating aging-in-place technology into the home will become more important—whether in apartments, shared living spaces, or traditional single-family homes. New monitoring devices, which may be covered by insurance in the future, could offer more connected care. Concerns for energy stability could lead to a greater need for renewable energy sources for these homes, which could shift infrastructure and planning needs. This would also affect zoning and need to be welcomed by the residents. For multifamily apartment buildings and complexes, automated systems and AI in smart buildings streamline maintenance and operations, reducing costs and improving performance. These smart homes can also offer curated personalization in new forms: through smart windows and new connected devices, they can bring community cohesion and bridge the gap for families that live in different places. This can also be utilized in co-living complexes and neighborhoods where residents want to share experiences.

1ST YEAR ON THE LIST

SMART PARKING AND ROADWAYS PREDICTABILITY

WHAT IT IS

Traffic congestion is one of the top concerns many municipalities hope to address with smart technology. They are also implementing new technology that can help generate less carbon dioxide with more efficient traffic patterns.

HOW IT WORKS

The structures and roadways in smart cities continue to provide opportunities for both data collection and improved resident experiences. Eventually, traffic lights could be used to monitor congestion and report when accidents occur, according to a recent patent. The proposed patent is also examining how traffic lights can connect to emergency services should an accident occur. Cities are exploring solutions for intersection congestion: for instance, Seoul is implementing a combination of AI, lidar, and CCTV at an intersection to enhance traffic signaling for improved safety. Parking spaces—whether in garages or on the street—are also data points that allow for potential visibility into available spaces within smart cities. Southwest of Denver, Colorado is testing interlocking Smart Pavement slabs that use Wi-Fi and detect when a crash occurs, which will then alert emergency services. In a recent study in the International Journal of Grid and High Performance Computing, researchers proposed an IoT-AIPS system that can predict parking spot availability to help reduce wait times for finding parking. HaydenAI took this a step further and, in collaboration with New York City, used the technology to detect illegal parking in bus lanes.

WHY IT MATTERS

Finding a place to park has always been a challenge in major cities, but new technology can alleviate this concern. It can also increase a sense of safety in more remote locations, with the implementation of these new traffic signals. Countries with a more mobile populace should prioritize these types of technologies to enable better experiences on the roads and create higher safety standards. This trend could also impact traffic patterns, where local jurisdictions might need to create plans, and then communicate any changes through connected devices and autonomous vehicles. The connected monitoring devices and traffic lights could ultimately take away emergency vehicle drivers' worry about crossing through intersections, at least when autonomous vehicles scale. In the meantime emergency personnel can gain a view into the current condition of their destination site they are going along with how to get there.

UBIQUITOUS SENSOR DISTRIBUTION

WHAT IT IS

Sensors are being further integrated into the built environment to collect data that can be used in predictive models and enable intensive and ongoing monitoring.

HOW IT WORKS

Sensors have become ubiquitous. In smart cities, IoT sensors and devices are embedded to collect data for operational use and predictive models. To fuel this connectivity, there have been several new network deployments, like Amazon Sidewalk, which aims to create a low-power, long-range network from IoT devices. In Scotland, the Aberdeenshire Council is trying out North's IoT Accelerator Pack program, which will reveal insights on building health, social housing, water monitoring, waste management, air quality, and road surface temperature.

As connected data collection in smart cities has increased, so has resident engagement. In Israel, Nexar and MuniAI are operationalizing IoT sensors and citizen feedback to alert city workers to maintenance issues. In the UK, Visual Solutions launched a crowd-sourced measurement service that uses mobile Wi-Fi signals to sense and count crowds. Sensors and AI are being integrated into safety vests for construction workers to reveal their location and excessive body heat, or integrate wearable detection methods to prevent people from being hit by cars.

Other companies are continuing to use sensors to predict air quality and pollen distribution, like Norwegian startup Airmine. Companies are also embedding sensors into IoT predictive HVAC systems to increase building performance and tenant experiences. Water quality technology also increasingly uses sensors for monitoring water and detecting lead and other toxins. In interior spaces, furniture and even walls are becoming embedded with sensors for data collection. A patent for a new office chair uses sensors in combination with more reactive fabrics and materials to tell when the occupant is stressed and needs to take a break.

WHY IT MATTERS

IoT connection is increasing the amount of data available to smart cities, and the industry is currently prioritizing water, traffic, and resident experience and safety. As sensors in the built environment begin to share more data between themselves, this will create greater opportunities for managing increasingly granular needs within the city. This also presents greater data security needs, and the necessity for residents to opt in to data collection. Without residents' consent and understanding, a pervasive sense of fear will arise over how their data will be used. Cities implementing these sensors should create robust campaigns to dispel concerns, and create plans to deal with potential sensor system hacks. New talent may be necessary for integrating the design of these sensors into projects; they also require an increased amount of IT investment in the office and on-site. Ultimately, sensors will provide a more continuous awareness of project status, which would solve a persistent client need.

DIGITAL TWIN PREDICTIVE PLANNING AND PREVENTION MONITORING

WHAT IT IS

Digital models are not new to the built environment industry. However, as they evolve, they are becoming more integral for upfront planning by enabling the constant flow of data about the long-term visibility of a structure, building, or product's life and use.

HOW IT WORKS

Urban transportation has been a major user of digital twins, with companies like ShapesAI using the technology to predict collisions. Cities and countries are also leveraging these models to predict when roads will need repair, and when traffic could occur. Estonia is rewriting its road maintenance manual using digital twins, and a new patent explores embedding sensors so that digital twins can predict settling and cracks in the road. In the US, startup Citydata utilizes AI to collect census data to look for patterns in transportation and population movements.

Urban planning has also been affected. Los Angeles is creating a digital twin of a neighborhood to test out decarbonization strategies, and new research from the University of Twente in the Netherlands found that digital twins can help improve the efficiency of planning and coordination in cities. This technology can be a boon to cities looking for new residents, which is what Miami is using its digital twin to do—helping them find schools and other amenities when they are looking to move. Jacobs in the UK is using digital twins to model potential floods to help communities know where to place key infrastructure. For interior spaces, Matterport recently launched Genesis, a generative AI that creates a digital twin of interior spaces to help property management teams make design and utilization decisions about physical spaces. The Korte Co., a US construction company, uses its data and digital twins in preconstruction to model what changes to parameters will do to costs and construction schedules.

WHY IT MATTERS

Digital twins and models are becoming an expectation within the built environment. However, the players who will most benefit from the technology are finding new ways to collect data that these models can use to generate meaningful insights. They'll be able to identify potential issues and make informed decisions even before issues arise or construction begins. The technology also enhances the design process and improves communication among project teams as they can model the repercussions of their decisions. Many working in BIM models will need to elevate their current level of modeling to achieve a true digital twin; when the digital twins link to become a digital mesh, it will signify the next evolution of this trend. When digital meshes become a reality for the built environment, that is when smart cities will truly become responsive and enabled. But this trend isn't just for new or smart buildings: Local firms can leverage their on-the-ground locations to start modeling older buildings, allowing them to have their own digital twins.

ENABLED DEVICES FOR URBAN MANAGEMENT

WHAT IT IS

New technologies such as edge drones, connected cameras, and novel communication systems are being used to enhance urban management processes.

HOW IT WORKS

Smart cities are leveraging multiple types of devices to monitor and detect events. One example is a new camera from Vivotek that uses a vision-processing chip and platform called BrainChip to utilize edge computing. It also uses AI to identify gender and age from video footage, even when people are wearing masks. Hailo Technologies in Tel Aviv is also exploring smart cameras that use edge AI processors for smart cities, security, retail, and other applications for analytics at the edge.

Drones are now also bringing smart city capabilities to rural areas, and a patent is exploring the potential for drone air and water monitoring. Light poles, like Voltpost, are transforming lamp posts into charging stations for drones and security monitoring stations; their cameras can also analyze images to determine if a pedestrian is in distress. Other Smart Poles from Vitrulux are also incorporating voice assistants, which could help pedestrians with navigation.

In Boston, Soofa digital kiosks provide air quality updates throughout the city and can even suggest what activities are safe to do outside. Bettair in Spain uses a network of sensors to map and identify pollution hotspots. In Houston, the city is using smart meters to track water usage and monitor its water distribution system.

Trash and waste management systems in smart cities also continue to improve. In the UK, the Sunderland City Council is testing out the use of solar-powered smart compactor bins. A recently filed patent is exploring using sensors and AI to help plan more efficient routes for garbage collection in cities, and for the detection of waste bins in the street.

WHY IT MATTERS

Improving the quality of life is a fundamental part of the built environment industry, and new technology makes that goal even easier for professionals. Real-time monitoring can detect and respond to security threats or emergencies, ensuring the safety of citizens. Monitoring of utilities like water and electricity can also allow for more efficient resource use and can help in early detection of issues like leaks or outages. What will be key here is the interoperability of these devices, so that they can communicate and share information. If multiple competitors begin to take hold in one region, future sharing of data could be problematic. Governments will need to carefully consider new regulations as the trend scales, and any new guidelines should be coordinated among local, national, and international entities so that new devices can be compliant in multiple regions. This will ultimately allow for more global interoperability and sharing of information, which could become crucial during times of global crisis. Well-monitored cities will also attract more businesses due to a better enabled environment and happier, healthier residents.

SCENARIOS

The New Way to Walk

On any given day in London, it is now quite common to see mobs of people gathering and walking down the street. However, this isn't your usual tourist crowd or flash mob. Instead, it's due to Zwift's route automation, which directs residents to take certain routes throughout the city to optimize their route in real time. Such a capability was attempted in 2023, with Transport for London's initiatives aiming to fix traffic congestion and address air pollution and climate issues, but it met heavy resistance after charges and fines were levied.

Most residents feel Zwift has taken this initiative to the next level in 2038, as it has allowed them to sync their calendars, and it can also help them to gain access to public transportation and other amenities; the app then tells them which route would be the most efficient for their time, cost, and carbon neutral goals based on their day. The app also suggests the walking path that might best suit their health needs and that they might find most pleasant. Users rely on its air quality alerts for the areas to avoid.

With more people walking, sidewalks have leveled up. They now incorporate new built-in resting pads; when you need a break, the pads sense your fatigue and can fold up to create a place for you to sit and recharge your wearables. A favorite sitting activity involves experiencing the rewilding forest through AR, learning about local history and indigenous wildlife. This experience can be had on London's autonomous public transportation, too, which has become its own tourist attraction.

CONSTRUCTION PRACTICES

1ST YEAR ON THE LIST

MASS TIMBER CONSTRUCTION

WHAT IT IS

As one of the newer developments for more sustainable construction, mass timber construction is gaining attention as many studies and projects consider using its components in lieu of concrete and steel.

HOW IT WORKS

Mass timber construction is scaling, and a wide swath of new research indicates it can perform in extreme conditions and have sustainability benefits that were not previously known. In 2022, there were 139 mass timber buildings in the world eight stories or higher either complete, under construction, or proposed, according to the Council on Tall Buildings and Urban Habitat.

There are potentially several environmental and financial benefits. Recent research shows mass timber panels' inherent thermal properties could possibly simplify or replace a building's traditional HVAC system. Another study found wood can match concrete's performance in thermal mass design. And when cross-laminated timber is used to create a structural floor system, it could lower costs and possibly reduce the need for load-bearing walls and columns, per research from Clemson University.

In practice, mass timber is moving into new sectors, like hospitality. DLRGroup collaborated with designers, architects, and other experts to showcase a mass timber hotel prototype for the Marriott group—the hotel meets its stringent sound insulation standards, has a lower carbon footprint than concrete, ensures structural integrity, and aligns with the 2021 updated International Building Code for safety. And as the technology progresses, mass timber is reaching new heights. At 284 feet, The Ascent in Milwaukee is the world's tallest mass-timber building and is fully compliant with Milwaukee's building codes, including fire safety.

WHY IT MATTERS

Mass timber construction will allow buildings to last longer and perform better. With new exploration, the material can replace steel, act as a means to reduce material use and waste, increase carbon capturing, and provide new design flexibility. While most governments worldwide have yet to adopt wood-first laws, major economies are modernizing building codes, funding research, and promoting sustainable forestry to advance mass timber construction. As it increases, this form of construction will continue to grow as well. New regions looking to use this construction practice will have to study supply chain stability, and it's likely there will be greater stability and faster adoption in mature industry regions like Europe. For emerging markets, more mass timber construction could mean new jobs in both the construction industry and manufacturing.

Mass timber construction can also benefit users. Wood provides aesthetic beauty and mental health and wellness benefits. Utilizing mass timber can also position a business as a leader in innovative, sustainable construction methods, enhancing its reputation and market appeal. The ability for new structural spans also lends itself to enabling new design challenges and innovative solutions to explore.

NET-ZERO CONSTRUCTION

WHAT IT IS

Net-zero construction is about balancing carbon emissions during construction and over the life of a project. This can be done through monitoring energy consumption, as well as through what materials are used, how the materials are produced, and other carbon offset strategies.

HOW IT WORKS

The 2022 Global Status Report for Buildings and Construction report found that the building and construction sector's energy consumption and carbon dioxide emissions reached unprecedented heights post-Covid, accounting for over 34% of global energy demand in 2021. Net-zero construction and techniques could help reduce this industry's energy use, and there are already promising examples like the Lola Mora Cultural Center in Argentina. The center is described as being net-zero with advanced energy-efficient systems, such as wind turbines, solar panels, rainwater harvesting, and natural ventilation, which will allow it to generate 20% more energy than it consumes.

Net-zero practices are moving into material development for the built environment industry as well. Sweden's SSAB has introduced its SSAB Zero recycled steel: rather than burning coal in the process, this approach uses fossil-free electricity and hydrogen, targeting near-zero emissions. There's also a lot of potential in the concrete industry, including CarbonCure, which strengthens concrete by adding CO_2.

On the construction front, the electrification of construction machinery is advancing rapidly due to improvements in battery technology. Japanese-based Komatsu will soon roll out an electric excavator and a fully electric compact wheel loader; this machinery offers significant benefits such as enhanced air quality and noise reduction, making it suitable for both indoor settings and urban areas.

Direct air capture (DAC) has emerged as another solution for buildings seeking net-zero. While the US Department of Energy is advocating for DAC, the technology remains costly and energy-consuming, which could pressure cities to invest further in the necessary infrastructure. But the original form of DAC—sequestering carbon in plants—is still an option. In one interesting case, Barcelona-based TAKK Architecture completed a mobile garden designed to be relocated to areas with the highest carbon emissions in the city.

WHY IT MATTERS

Net-zero construction plays a pivotal role in modern building practices due to its significant impact on climate change mitigation, energy efficiency, and sustainability. By aiming for a balance where the total amount of energy used by a building is roughly equal to the amount of renewable energy created on-site, these buildings drastically reduce greenhouse gas emissions. Additionally, net-zero construction often incorporates elements that enhance indoor air quality and comfort, contributing positively to occupant health and well-being.

Projects that are carbon neutral or even carbon negative are growing in number. As more projects utilize net-zero construction practices, they will need access to more renewable resources. Future energy storage solutions that enable shorter durations for recharging batteries, vehicles, spaces, and equipment from renewable sources promise a transformative future for urban construction. Currently, approximately 253 global cities have net-zero targets, with half formulating plans. Many communities are also looking to become net-zero. They will have a growing need for sustainable infrastructure and collaboration as they seek out established goals.

ADDITIVE CONSTRUCTION

WHAT IT IS

The 3D and 4D printing of structures, materials, and buildings is becoming more of a norm.

HOW IT WORKS

The option to use 3D printing technology is revolutionizing the construction industry with notable examples around the world. Glasgow's "active transport" bridge, the largest printed concrete construction in the UK, showcases the potential for creating intricate and unique infrastructural components in bridge construction. Dubai's 3D printed office in the Emirates Towers highlights how this technology can save both time and money, and aligns with the city's goal of having a quarter of all buildings 3D printed by 2030. Telangana, India, is looking to blend cultural reverence with innovation, by building the world's first 3D printed Hindu temple. Meanwhile, in Texas, ICON is partnering with Lennar and Bjarke Ingels Group to develop the largest 3D printed community offering, which includes 100 homes.

But the technology is still evolving. Tech company RENCA has pioneered the use of geopolymers for 3D printing entire houses, and the EU-funded WOOL2LOOP project repurposed mineral wool, typically considered waste with low-recyclability, into geopolymer concrete for construction. Meanwhile, a research initiative at the Missouri University of Science and Technology aims to develop an AI program that determines the best locally sourced materials for 3D printed concrete. By testing a variety of fibers, including unconventional plant-based and recycled fibers, the program seeks to enhance local sustainability, reduce construction costs, and improve the efficiency and safety of military construction efforts.

Scientists have developed a new 3D printing technique that allows them to control the cell structure and influence the final product shape; though early in development, this sustainable, reusable wood retains its original properties including strength and scent. Researchers from Bath and Imperial College London introduced Aerial Additive Manufacturing drones capable of 3D printing buildings.

WHY IT MATTERS

With a global demand for new homes and a need to convert aging infrastructure into revitalized assets, additive manufacturing offers solutions. For overpopulated cities or suburbs looking to expand, the technology could provide avenues to develop sustainable neighborhoods quickly. This could lead to new ways for businesses to use additive manufacturing for repair, product manufacturing, and increasing construction speed. The compounds and materials that go in and come out of this construction type will become increasingly important for the built environment. The fact that waste is becoming a targeted material, could form new circular business offerings as well.

As additive manufacturing begins to generate more aesthetically pleasing materials, it will help acceptance. But as the technology scales, it will disrupt many traditional forms of design and construction, as it will offer new ways of creating and building. Such changes can bring customizable diversity to regions and for new homeowners, where they can choose from a menu of offerings made just for them. And by localizing production for product manufacturers, construction site selection could become more of a focus.

INTERACTIVE PROJECT MANAGEMENT

WHAT IT IS

Project management tools that allow for real-time monitoring and data transmission are creating efficiencies in construction. This includes the platforms themselves, as well as wearables that project visual data for workers as they build.

HOW IT WORKS

Studies have found that most general contractors use minimal automation for their subcontractor management processes. This leads to data silos, and contractors lose out on potential improved productivity, cost performance, and profitability. Autodesk Construction Cloud's (ACC) 2020 acquisition of Pype introduced AI-powered submittal logs, and now the company's launch of AutoSpecs in ACC can help streamline the construction processes for those just starting down this road.

On the front end of projects, management platforms for various tasks, like CoConstruct's integrated suite of construction estimating tools and STACK estimating software, are hitting the market. Join offers a platform that streamlines construction decision-making by importing data from tools like Excel and letting users evaluate the cost implications of preconstruction choices in real time.

For the building itself, management systems are not new. However, management systems that track efficiency are gaining ground. Learnd, a UK startup, is offering a unified building management system platform that integrates with existing systems to enhance energy efficiency and decrease carbon emissions.

New tools and platforms are also creating overlays that enhance project management. Argyle is an AR application for job sites that offers BIM visualization to prevent errors and ensure smooth project progression without the need for Wi-Fi. GAMMA AR uses augmented reality to overlay 3D BIM models on job sites. VSight is an AR-powered platform used by industrial workers for remote collaboration and knowledge access, streamlining operations in over 100 countries. OnSiteXR is a mixed reality app for HoloLens 2 that aids in attaching prefab building elements and records work using speech-to-text and image capture.

WHY IT MATTERS

Project management during the construction process is time-consuming and laborious. Addressing the challenge of workforce depletion, new platforms replace time-losing work processes so workers can focus on other needed workflows. More wearables that allow for the monitoring and managing of workers can also increase worker safety, and subsequently impact the bottom line of a company with reduced on-site injury claims. These wearables could become more standardized and interoperable, which would allow for more health management of the worker as well. Devices like these can not only prioritize on-site safety but also bridge communication gaps, enabling real-time access to data and fostering remote collaboration, leading to better project management. With more immersive technologies, the jobsite can now become interconnected with the model back in the office, which could allow for real-time drafting and designing coordination, replacing RFIs and even submittals.

SCENARIOS

Road Today, School Tomorrow

As with many developing countries, Kenya once struggled to balance building infrastructure over schools. The country needed schools to educate workers, but getting schools built and roads to get there also needed workers. This challenge persisted until the MIGA expanded its guarantees to help develop real-time monitoring for additive roadways. Through a partnership between investors, COBOD International, and several universities, they were able to create an offering that used real-time monitoring to know where roads would be most helpful, but could also be additively-made to be weather resistant. Once trade routes were established, the roads themselves could be converted into materials to build new schools. Once the schools have been established for several years, and repairs of the new roads become no longer feasible, the roads are recycled and ready for reuse for water management or other necessary infrastructure. This has helped Kenya to continue to develop while also managing some of the issues the country faces due to climate change.

SCENARIOS

SCENARIO YEAR 2040

Tag You Later!

"Day of Drafting," or Tag Day as it was first called because it emerged in Germany, has become a phrase many firms discuss when they talk about the history of construction documents. The combination of AI project management tools, AR drafting, and additive manufacturing combined in an unforeseen way to change the industry in the early 2030s. New wearables for drafting allowed connected professionals the ability to draft in an AR space; the design was then immediately run through an AI code check in the ConPro management platform, and, if it passed, printed on-site immediately. Gone are the days of waiting for permits and the right site conditions, thanks to the connected sensors on site. The sensors told the crew what was ripe for building on that day, and then the component was drawn and printed immediately. The drone workers helped by then taking scans of what was printed, comparing it to the model through the platform, and then asking the architect, engineer, and designer to sign off on it. Because of this new form of building, at the end of the day, most construction workers now sign off with, "Tag you later!"

MODULAR CONSTRUCTION

WHAT IT IS

Modularity has struggled to scale within construction, but has still continued to grow with its technical precision to include whole hospital suites that can be shipped and plugged into a new hospital building.

HOW IT WORKS

Health systems increasingly prefer modular and prefabricated construction methods due to their speed and efficiency. That's why M Health Fairview St. John's Hospital in Maplewood, Minnesota, used modular expansion to swiftly add 16 extra beds in nine months; traditionally, that project would have taken 15 months. As a project director at the University of Pittsburgh Medical Center, Michael Schesler is overseeing the construction of a 17-story inpatient tower that will use various prefabrication methods, with components like walls and bathroom pods being made in a nearby warehouse. A notable feature is the preassembly of horizontal MEP distribution systems, which are prepared in the warehouse, transported, and installed on-site. And even outside of hospitals, the ANNA Collection is taking modular living to a new level as its prefabricated cabins can be shipped anywhere.

The "polyroom" concept, developed by the French firm Cutwork, aims to tackle the looming global housing shortage with modular construction. The company builds small modular units with green spaces that can be swiftly assembled and reconfigured to adapt to daily needs, making it ideal for rapid urban development. For furniture, Ori specializes in robotic-powered space-saving solutions that transform single-use areas into multifunctional spaces.

Modular "jigsaw" roads, designed for rapid disassembly and reassembly, offer urban areas an adaptive solution to fluctuating traffic, construction demands, and emergency situations. CirculinQ, a Netherlands-based company, utilizes recycled plastic blocks for roads and pavements, efficiently managing water and showcasing impressive durability. Carlo Ratti Associati has furthered this concept with a modular street prototype, featuring hexagonal blocks that can be quickly rearranged, transforming a busy road into a community space like a basketball court.

WHY IT MATTERS

At scale, modular construction would address much of the renovation many cities will need to help prevent urban decay. As residents move from downtown areas, they are looking to modular homes in suburban areas. Modular construction can offer complete customization and be shipped anywhere in the world, which, with a growing mobile population would be very attractive. Communities may become more ephemeral, and prefabricated neighborhood setups may need to be ready. While upfront costs can be higher, the rapid construction timeline offers quicker delivery. With a growing unhoused population, modular units could be used to add on to existing structures in a cost effective manner that would not hurt the building's existing function or a multifamily residence's performa. It can also help minimize disruption when spaces need to remain open—like emergency rooms.

AUGMENTED CONSTRUCTION

WHAT IT IS

The use of robots and other automated processes is changing construction practices and reporting, reducing project timelines, as well as reducing worker risk.

HOW IT WORKS

Cobots, the robotic coworkers, are becoming an established presence on many job sites—and they come in all sizes and for multiple functions. San Francisco-based startup Canvas leverages robotics, AI and machine learning to enhance drywall finishing and painting. This compact robot, roughly the size of a kitchen stove, is outfitted with laser scanners and operates on a vertical platform to navigate unfinished structures. Ken Robotech's Tomo-robo is a handheld tool designed to automate the repetitive task of rebar tying in construction, enhancing efficiency and alleviating the physical burden on workers.

Boston Dynamics has unveiled a substantial update to its Spot robot dog, by introducing advanced inspection workflows, enhanced interactions with humans, autonomous door manipulation, and a new vocal capability powered by ChatGPT and other AI models, which can boost its efficiency and user-friendliness. The Ddog project from MIT Media Lab combines Spot with a Brain-Computer Interface system, utilizing AttentivU's wireless glasses to measure brain activity and eye movements for nonverbal communication. While not in use on the construction site, yet, if successful it could aid in tasks all controlled through brain signals—and potentially be a game-changer for those with physical challenges.

Ballast Nedam, in partnership with ROPAX, launched a masonry robot in late 2021 to boost the efficiency of residential housing construction. It can measure a facade in 15 minutes and ensure level masonry even on unstable scaffolds, saving a day's work per facade. The Hadrian X, developed by Australian-based FBR Limited, is a swift and efficient mobile robotic blocklaying system capable of constructing house walls within a day using 3D CAD models. Beginning in 2025, HD Hyundai plans to broaden its Xite technology, which will enable greater site connectivity in the construction, demolition, and mining industries.

WHY IT MATTERS

As labor continues to be a challenge, integrating robotic and augmented processes can reduce the need for staff on-site. This can be helpful in developing regions where workers are scarce, but they may need to consider partnering with companies to bring the tools and technology to the region. Augmented construction by way of cobots could allow for continuous repair of aging infrastructure. While manufacturing already uses robotics in the production of many of its products, the built environment products may soon need to contend with figuring out how to teach cobots how to install their sometimes delicate products. Construction tolerances will need to be updated as more cobots perform the tasks, either negating the tolerance altogether or increasing them depending on the task the cobot is performing. Lastly, while safety may increase in some areas, in others it may decrease with the use of the cobots, which could mean a change to insurance premiums.

SCENARIOS

Nostalgia-Made Spaces

As many homeowners struggled to find homes in the early 2020s, they would often complain that the homes they could find were nothing like the ones they grew up in—and they cost twice as much as they could afford. Enter Nostalgia Homes, a developer that started out working with new parents who wanted to re-create the home they grew up in, so their kids could share the same memories they experienced decades ago.

Nostalgia Homes started in Austin, Texas, and soon became a global developer after completing its first 3D printed neighborhood. The company impressed clients with its details and accuracy. Through AI simulations, couples were even able to blend the best parts about each other's childhood homes and share that blended experience with their family. Not to leave urban clients out, Nostalgia Homes soon spun out Nostalgia Apartments and even Nostalgia Venues for repeating travel memories. The company could go into a modular blank apartment and retrofit the empty space using additive drone swarms to look like any place the tenant had previously lived. Nostalgia Venues offers the ability to re-create destination locations where couples were married or where a family had vacationed together. Some of the venues are going even further, using AI simulation to help find ways to build portions of international landmarks in other countries to help those who cannot afford to travel.

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Mark Bryan is a Senior Foresight Manager at the Future Today Institute and leads our Built Environment, Hospitality, Retail, Restaurants & CPG practice areas. Mark excels in applying strategic foresight to design and the built environment, anticipating future need states for our physical and organizational spaces. His expertise in integrating strategic planning with innovative design principles empowers businesses to anticipate and adapt to future trends, fostering sustainable growth, resiliency, and transformative change in their industries.

Before FTI, Mark worked as a workplace strategist, designer, design researcher, and futurist for clients across the country, most recently through his role as Director of Innovation + Research at a design and architecture firm.

Mark's portfolio of clients includes national foundations, global CPG companies, international associations, product manufacturers, national retail brands, multi-family developers, healthcare systems, senior living facilities, restaurants, and large multinationals. Mark has produced original research and strategic analysis on the future of co-living, senior living, workplaces, play, hotels and resorts, dining, and distance learning.

Mark is a coach in the strategic foresight MBA course at the NYU Stern School of Business. He holds a BS in Interior Design from Virginia Tech and NCDIQ Certification.

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NEWS · INFORMATION

Future Today Institute

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TOP HEADLINES

The news ecosystem is at an inflection point. The adoption of generative AI in business and entertainment media is actively shaping consumer expectations for news.

01 **Generative AI is mainstream**

While algorithms won't completely replace human creators in the near term, they are lowering the barrier to creating compelling content.

02 **Digital traffic dynamics are shifting**

Websites built on search will need to contend with rapidly shifting consumer behavior, driven by a flood of algorithmic content and changing search modalities.

03 **Publishers are losing power in the content value chain**

Technology companies are poised to claim a greater share of the content value chain wielding multimodal LLMs, giant troves of scraped data and the power of AI summarization.

04 **Foundations are the new hedge funds, offering an influx of cash to fund journalism**

News organizations, especially public media and local outlets, are counting on those grants to hire staff and grow.

05 **Trust is essential for media businesses, but it is at near-historic lows**

The ability for legacy publishers to succeed will hinge on their ability to maintain the trust of audiences.

STATE OF PLAY

Emerging technologies like generative AI are shaping the future of content creation, distribution and monetization.

Generative AI went mainstream in 2023, igniting fears that algorithmic content would flood the internet and relegate writers to the dustbin of history. In the year ahead, the initial frenzy around ChatGPT, prompt hacking and AI-backed product launches will fade, but the information ecosystem will never be the same.

As technologists search for new applications of AI, the media value chain is being reshaped. The barriers to creating compelling content are falling because of AI-enabled editing tools—which include text editors that can draft paragraphs from bullets and video editors that can synthesize a sizzle reel from a few words.

Norms of digital distribution shaped over the last decade are crumbling. There is no longer a dominant social network for news. Search traffic with generative summaries are poised to replace the traditional list of links. That concern is on top of a shift in Google's core algorithm that has reduced the visibility of news websites.

At the same time, the fundamentals of the information economy remain challenging. The move to reader revenue has kept lots of publishers afloat, but it remains to be seen how much growth is possible. There is substantial excitement around philanthropic funding models for journalism, but nonprofit newsrooms still need to prove their relevance to audiences.

KEY EVENTS

MARCH 2023

LLM explosion
Generative AI fever hits with
the release of multiple LLMs
(large language models),
including GPT-4.0.

MAY 10, 2023

Generative search from Google
The launch of Search Generative
Experience highlighted how AI
might change news discovery.

DECEMBER 13, 2023

Axel Springer + OpenAI partner
The German media house became
the first global publisher to reach
a licensing deal integrate its
journalism into OpenAI's products.

APRIL 12, 2023

NPR quits Twitter
NPR's departure emphasized
the dramatic shift in the social
network's tone and leadership.

MAY 18, 2023

Section 230 remains intact
The Supreme Court ruled
technology platforms aren't
liable for user-generated content.

LIKELY NEAR TERM DEVELOPMENTS

THE PACE OF CHANGE ACCELERATES

Journalists are accustomed to the breakneck pace of change: Adjusting to rapid developments has been the watchword of media organizations for more than a decade. The year ahead will test whether news leaders have learned to search for disruption or whether they've gotten complacent. Barriers to creating compelling content will fall. The operating assumptions that let many digital publishers thrive on reach will crumble. There will be a race to derive value from existing content, either by licensing it to tech companies or building publisher-owned LLMs. New categories of devices will demand new publishing formats. Successful news organizations will triage these competing threats to find opportunity; too many publishers will do nothing and find their relevance diminished.

Evolution in copyright law

Generative AI tools have outstripped settled law. Expect to see litigation challenging whether crawling content to train a large language model constitutes fair use. The impacts of that legal wrangling could be compounded by new laws or regulations.

New modes of search and discovery

Generations Z and Alpha have different consumption patterns than older generations. These differences are especially stark when looking at how younger users find news. Publishers need to tailor their strategies to reach those potential consumers.

Fragmented information access

Not everyone can afford a news subscription. As paywalls at premier publishers get tighter, essential reporting may not reach the communities that need to see it. This is of particular concern for the 2024 US presidential election.

Subscription fatigue

The conversion to a subscription economy is happening in news but also in retail, gaming, automobiles, and more. All those programs are competing for a finite share of consumer spending, so publishers need to ensure they are essential to remain competitive.

New European regulations

The EU's Digital Services Act, in effect since August, introduced substantial changes to the regulatory framework for tech platforms. Its obligations may shift how platforms operate, just as a Canadian law caused Meta to drop news from its platform last year.

Easier content creation

Expect to see a new suite of productivity tools aimed at transforming the creative process. Those tools will have a cultural—and economic—impact as they lower the barriers to publishing text, photos, and videos. Legacy creators will struggle to adapt.

11 MACRO SOURCES OF DISRUPTION
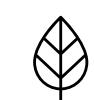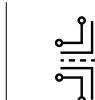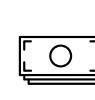
Technology	Media & Telecom	Demographics	Environment	Government	Public Health	Education	Geopolitics	Infrastructure	Economy	Wealth Distribution

WHY NEWS & INFORMATION TRENDS MATTER TO YOUR ORGANIZATION

Search and discovery is relevant to all

Any business that publishes online—effectively, anyone with a website—needs to understand how consumers search for and discover new information. The shifting search and social media landscape is particularly important for publishers but is broadly relevant because those changes will quickly impact other industries.

Businesses cannot operate without journalism

A growing body of research shows that losing local news outlets leads to more corruption, less competitive elections, and weaker government finances in impacted regions. Business leaders need to follow news and information trends so they can maintain the health of their operating environment.

Consumption highlights consumer behavior

The way news is read, watched, and listened to offers tremendous insights into how consumers will interact with technology more broadly. The pervasiveness of news makes it a good barometer for understanding how consumers will adapt to new devices and media formats.

Content verification

The ease of creating content with AI tools means that it is more important than ever to verify the authenticity of facts, images, and videos that circulate online. Journalists aren't the only ones responsible for fact-checking—any organization that publishes content online or takes strategic actions based on open-source information needs to do it.

Sustainable news funding is essential

It is critical to understand how the economics of news will continue to support impactful reporting. The last five years saw a substantial shift in how publishers fund themselves, with renewed emphasis on digital subscriptions and foundation support. Those developments have important repercussions for the entire media value chain.

Understanding the dynamics of trust

Trust is an essential asset for all businesses, but news organizations must pay special attention to their credibility. Tracking trends in news and information can help an organization understand and respond to the ways that technology is driving audiences to become more polarized and distrustful.

OPPORTUNITIES & THREATS

Threats

Reader revenue programs will face growing competition in a market saturated with subscription products. Publishers may fail to diversify their revenue streams because of the industry consensus to keep pursuing audience revenue.

Search engines that incorporate generative AI or voice interfaces may send less referral traffic to news websites. That will curtail one of publishers' strongest tools for reaching new audiences, restricting future growth.

Device manufacturers and platforms may use LLMs to generate and distribute news directly to their users. The result would be a dramatic shift in the media value chain, threatening to displace publishers' core offering.

Trust in institutions—and in news media in particular—remains near historic lows. News organizations that lose credibility won't be able to build audiences to sell advertising or to convert consumers to subscribers.

Resource-constrained publishers struggle to track the innovation related to content creation and distribution happening across domains. Their organizational culture makes it difficult to respond to multidisciplinary challenges.

Opportunities

Legacy publishers have a deep archive of content that can be used for training large-language models. The demand for data to train LLMs could increase the value of those archives, creating a new revenue stream for publishers.

Brands that maintain durable relationships with consumers will thrive in a low-trust environment. Publishers that have built trust over decades can translate that across distribution channels with thoughtful product development.

Emerging devices will demand new programming formats. Creators and publishers that act on that opportunity early will be able to set norms and negotiate better deals with platform companies than those that delay action.

Technologists across the world are seeking ways to enhance and apply AI tools like ChatGPT. That means media companies have an unprecedented number of potential partners to work with on product development.

Many open-source alternatives to AI models licensed by tech giants like Google, Microsoft, and OpenAI are available. The propagation of open-source language models could allow news organizations to innovate with greater control.

INVESTMENTS AND ACTIONS TO CONSIDER

1

Assess the value contained within your archives. Is there an opportunity to license that content or use it to train your own large language model? Does that content have specific biases that should be addressed before it could be used in production? Is the archive already digitized or is it analog?

2

Ask how your organization would respond to a trust crisis: What would you do if your website was used to launch a coordinated misinformation campaign? How would you recover from a mistake that impacts consumers' perception of your brand? An internal exercise could expose operational gaps before they have consequences.

3

What skills will your organization need in the next 5-10 years? How will you be able to train or recruit staff who can support and execute on your goals?

4

Understand the audiences you are trying to reach and invest in building direct relationships. If your strategic plan calls for an audience of younger users, how will you measure that goal? Once you start making inroads with that audience, what tactics will you use for keeping them engaged?

5

Build partnerships with a local university to identify and create technical infrastructure. Connections with academic institutions can help to make sense of state-of-the-art research and create a talent pipeline for your organization.

6

Identify the tasks most vulnerable to automation within your organization. Would deploying an AI tool to automate that work increase operational risk? How would your consumers respond if they learned that certain text was generated by an algorithm? Honestly answering those questions could help triage pilot projects.

CENTRAL THEMES

Weakening legacy organizations

The information ecosystem is less resilient because of waves of consolidation and layoffs that have buffeted publishers. More than half of the local newspapers in the United States are owned by just seven companies. 2023 was a brutal year, with more media layoffs recorded by July than any year on record, according to career services company Challenger, Gray & Christmas.

Across the media landscape, legacy players and digital upstarts are redoubling their efforts to build audience-funded recurring revenue streams. That work is essential, but it is a long way from reversing the losses that publishers—especially those providing local news—have suffered over the last decade and half.

As a result, organizations are forced to make difficult choices between forward-looking innovation and core operations. While it's easy to defer investing in emerging technologies and platforms, the strategic imperative is to act on the trends nearing an inflection point.

Pivot to audience revenue

Subscriptions power media outlets, from multibillion-dollar media giants like The New York Times to individual passion projects on Substack. They are a preferred tactic with news organizations because they align publishers' economic interests with their audience.

Publishers are getting more efficient at converting readers to subscribers—and understanding how to retain them once they've signed up. Those insights are essential for news organizations striving to remain sustainable.

At nonprofit news organizations, which generally don't charge for subscriptions or have a paywall, audience revenue is also an important source of support. At those organizations, the challenge is demonstrating the value of recurring support without the help of a paywall.

Whether it's a subscription or a recurring donation, news organizations need to focus on providing an essential service. That's the best way to ensure consumers stay engaged and remain willing to pay, even as more and more other industries launch subscription programs to compete for readers' limited funds.

Preserving civic information

Widening news deserts in the United States make it harder to find basic coverage of local governments. The influx of philanthropic funding to news is driven, in large part, by a desire to reverse that decay.

"The philanthropic sector recognizes the need to strengthen American democracy," said John Palfrey, president of the MacArthur Foundation, in the launch announcement for the $500 million Press Forward coalition, to be used for local journalism. "Progress on every other issue, from education and health care to criminal justice reform and climate change, is dependent on the public's understanding of the facts."

Another, less discussed, need is preserving open access to essential information about basic services and emergency situations—information that can be difficult to find because of the quality of government websites and other official sources. The current wave of philanthropic funding for news isn't directly addressing this issue, but emerging broadcast standards could help.

Focus on value, not tools

Nearly every day a new startup launches with a novel application of AI. Those tools increasingly seek to change how would-be creators operate. While some products will truly disrupt the information ecosystem, it is far too early to know which ones will have a durable impact.

Instead of focusing on the specific application of technology, look for whether it offers a fundamental shift in how value is created. An AI-enhanced word processor may reduce writer's block and streamline the writing process. Rather than analyzing the ethics of publishing AI-powered suggestions, news organizations should consider the implications of inviting tech companies into their value chain: How might a magazine's distinctive voice be impacted if its writers use the same off-the-shelf editing algorithm that another publication uses? How will pre-publication data be used in other products or services?

ONES TO WATCH

Ashley Alvarado, who leads community engagement and strategic initiatives for Southern California Public Radio, for pursuing innovative ways to engage audiences with public media.

Keith Axline, Spencer Cavanaugh, and **Eric Mack,** co-founders of JournoDAO, for prototyping ways that journalists can engage with Web3 technologies.

Scott Brodbeck, founder of a local news network serving the Washington, D.C., metro area, for experimenting with GPT-4 to scale local news operations with low-code automation.

Meredith Broussard, data journalist and journalism professor at New York University, for academic research on applications of AI to investigative reporting and the creation of ethical AI.

Feli Carrique, executive director of the News Product Alliance, for coordinating a community of news innovators, including launching a new certificate for News Product Management.

Jon Cohrs, Chris Wood, and **Willa Köerner,** members of The New York Times R+D team, for work on spatial audio, including creating a guide for podcast producers to use the technology.

Liz Danzico, design executive at Microsoft, for contributing to the development of Bing's AI interface and working with news organizations to consider how they need to evolve.

Jessica Davis, senior director for AI prodect at Gannett, for pursuing AI-powered newsroom automation solutions across the publisher's network.

Lebo Diseko, South African correspondent for the BBC World Service and Nieman Fellow, for research into new modes of audience engagement and how journalists can protect democracy.

Evelyn Douek, assistant professor of law at Stanford Law School, for leading scholarship on how online speech is regulated by social platforms and tech companies.

Dr. Magdalena Fuentes, professor at NYU, for research around how AI can improve the quality of closed captions and transcriptions by better describing ambient sound.

Uli Köppen, head of the AI+Automation Lab at the German public broadcaster Bayerischer Rundfunk, for prototyping and exploring the future of public service broadcasting.

Joy Mayer, director of Trusting News, a project that trains journalists and conducts research intended to help bolster trust in and credibility of news organizations.

Miranda Marcus, leader of BBC labs, for managing the broadcaster's innovation incubator that explores new ways technology can support newsgathering and distribution.

Surya Mattu, leader of the Digital Witness Lab at Princeton University, for work supporting technologies investigating misinformation and how algorithms make decisions.

Dr. Swapneel Mehta, founder of research collective SimPPL, for facilitating partnerships to understand local news audience analytics and the spread of disinformation.

Dr. Arvind Narayanan, professor of computer science at Princeton University, for leading a research project about algorithmic amplification on social media.

Michael Newman, director of transformation at Graham Media Group, for leading a project that experimented with using generative AI to improve the quality of comments sections.

Josh Raab, former director of Instagram and TikTok at National Geographic, for studying how journalists can understand social algorithms as part of a Knight-Wallace fellowship.

Zach Seward, the New York Times' first Editorial Director of A.I. Initiatives. In that role, he will play an outsize role shaping the norms for how one of the world's largest news organizations uses AI tools.

Felix M. Simon, doctoral student at the Oxford Internet Institute and Knight News Innovation Fellow, for researching the blind spots in newsrooms' AI guidelines.

Agnes Stenbom, founder of Schibsted's inclusion lab, for advancing research into responsible AI usage and for prototyping ways outsiders can get involved with the future of news.

Dr. Benjamin Toff, senior research fellow at the Reuters Institute for the Study of Journalism, for leading research into declining trust in news in communities around the world.

Johanna Wild, founder of Bellingcat's investigative tech team, for nurturing the ecosystem of developers and tools that can improve the quality of investigative journalism.

REPORTING + VERIFYING INFORMATION

3RD YEAR ON THE LIST

COMPUTER-DIRECTED REPORTING

WHAT IT IS

Publishers are becoming more comfortable with applying AI in the newsroom. Increasingly, forward-looking news organizations are using algorithms to identify newsworthy events and develop story pitches. The trend could make reporters and editors more efficient but only with careful oversight to prevent infusing reporting with algorithmic bias.

HOW IT WORKS

Experimental tools powered by AI are finding their way into newsrooms. Newsquest, the second-largest newspaper company in the UK, hired an "AI-powered reporter" in June. When the job description was posted, Newsquest's Editorial Development Director Toby Granville told a media blog: "AI technology opens up new possibilities for newsrooms, helping them win back time to focus on what they do best—face-to-face journalism, which can never be replaced by robots."

The Associated Press launched five pilots to showcase the applications of AI within local newsrooms, with funding from the Knight Foundation. Those included working with the Brainerd Dispatch in Minnesota to generate automated summaries of police updates and triaging press releases and tips sent to WFMZ-TV in Allentown, Pennsylvania. Another project at WUOM-FM at the University of Michigan built a system for sending reporters alerts when certain topics were discussed at city council meetings.

ALXnow, an Arlington, Virginia-based local news website, used OpenAI's GPT-4 to launch an AI-written newsletter and build a copy editing tool. YESEO, a project sponsored by the Reynolds Journalism Institute, uses GPT to suggest search-friendly headlines for news articles.

WHY IT MATTERS

The accelerating capabilities of generative AI raise existential questions for publishers and threaten to destabilize the content ecosystem. Those concerns should be top of mind for news leaders, but they are also relevant for anyone who consumes the news.

There are already examples of how generative AI strategies can go wrong without proper oversight. After backlash about the decision to publish more than 70 articles written by AI, CNET launched an internal investigation to review those stories. More than half—including articles with titles like "What Is Compound Interest?" and "How Much Should You Keep in a CD?"—needed corrections. In some cases, CNET also had to rewrite the articles because the investigation revealed some of the language had been plagiarized from the sources used to train its model.

A growing number of news organizations are releasing AI policies to govern their use of algorithmic tools. The guidelines generally deal with the production of content, leaving many open questions about other AI considerations. Those include whether newsrooms might become increasingly dependent on the technology companies providing AI solutions and how news organizations can ethically use all the data they collect from their audience and in the reporting process.

3RD YEAR ON THE LIST

DATELINE: METAVERSE

WHAT IT IS

Even as the hype for metaverse products fades, the line between our digital and physical selves is increasingly blurred. News organizations need to be prepared to report on events that unfold seamlessly across the real world and digital platforms.

HOW IT WORKS

More and more of our lives are spent in persistent digital spaces. Reporting on the metaverse means taking seriously the events that happen in those digital worlds instead of relegating them to a niche beat like "internet culture" or "gaming."

In February 2023, a Colombian traffic court convened to hear a case in the metaverse—an apparent first for the judiciary. Participants in the dispute appeared as avatars in Meta's Horizon Worlds platform, with a live steam broadcast to YouTube. The presiding judge, Magistrate María Victoria Quiñones Triana, appeared as an avatar dressed in black robes.

Together, a handful of newsrooms launched projects on The Sandbox and Decentraland, two gaming platforms with metaverse-like qualities. The South China Morning Post used The Sandbox to publish a collection of historical photos, data visualizations, and illustrations as NFTs. British business magazine Management Today published its March 2022 cover as a 12-meter high wall in Decentraland.

One persistent challenge for news organizations operating in the metaverse is the lack of established norms around content moderation. Each virtual platform has its own rules and enforcement mechanisms—to the extent that there are any. That creates uncertainty for brands looking to launch experiments and makes it harder for reporters to identify truly newsworthy events.

WHY IT MATTERS

Covering virtual worlds seriously requires reframing how we think about them. If a political candidate appears at a rally saying one thing but their avatar contradicts that statement in a virtual world, how should journalists respond? Is the in-person comment more "real" than the digital one? What if the doublespeak is part of an intentional messaging strategy?

Newsrooms need to expand coverage of virtual spaces beyond the gaming beat—behind the press releases and cartoonish graphics, reporters will find tangible investments in technology, talent, and infrastructure by some of the world's most powerful companies.

News organizations should also start thinking about their long-term value proposition in the metaverse: As we spend more of our lives connecting digitally, how do real-world connections change? How can local newspapers create relationships with citizens who see themselves more connected to an online affinity group than to their neighbors in physical space?

Without a single dominant virtual world among consumers, organizations considering metaverse experiments need to be cautious about where they invest. Rather than doubling down on a single platform, executives should consider how to develop the underlying skills that will be necessary to succeed, no matter which platform becomes popular.

SUMMARIZATION AT SCALE

WHAT IT IS

Generative AI excels at consuming content and transforming it. Products are already on the market that use large language models to summarize text for a streamlined reading experience. Researchers are looking to extend that approach to video. This trend jeopardizes the creativity and voice that lets high-value publishers differentiate themselves.

HOW IT WORKS

Summarization is one of the tasks at which LLMs excel. Researchers are actively developing benchmarks to evaluate how well those models perform—both in relation to one another and in competition with humans. One project by a research team from Stanford and Columbia universities found that evaluators ranked AI-generated summaries as highly as those written by trained freelancers.

One of the most active research domains is "multimodal summarization"—a summary that takes inputs from multiple forms of media or was created in a different medium than the source material. For example, generating text summaries of videos or generating a video highlight reel using a combination of raw footage and news stories.

There are also aggressive pushes to productize summarization. Artifact, a news reading app launched by the founders of Instagram, includes a feature that generates a bulleted summary of the articles it curates. In principle, that can be a valuable service for readers, letting them catch up quickly on the news. In practice, however, summarizing news can be difficult: The generated summaries sometimes express a quote as a statement of fact. That can materially change the meaning of the story, especially on sensitive topics like crime coverage.

WHY IT MATTERS

Summarization seems like a simple task, but effective summaries need to balance competing interests: A good one is clear while staying true to the original. Source texts might be packed with distinctive writing styles, metaphors, and subtle meanings. A news article might include a mix of factual statements, quoted opinion, and expert speculation.

In a crime story, an AI model might mistakenly transform an allegation from the district attorney into a statement of fact, dramatically changing the meaning of the original reporting and potentially generating libel if the accused is innocent. A lawsuit filed in June tried to test whether AI can be held liable for such errors: A Georgia radio host is suing OpenAI, alleging that a summary produced by ChatGPT falsely accused him of embezzling money from a gun rights nonprofit. The case was dismissed for procedural reasons; other similar cases will follow.

The power to crawl and effectively summarize information could create a new intermediary between publishers and their audience. AI may make it possible for readers to consume far more information than ever before. The question for publishers is whether that interest will generate any new engagement for them—or whether all of the consumption will happen on enhanced search result pages, in reading apps, or in platforms that haven't been invented yet.

1ST YEAR ON THE LIST

CONTENT VERIFICATION

WHAT IT IS

Generative AI is creating new challenges for journalists. As the cost and complexity of creating realistic fakes decrease, the need to be skeptical of images and videos circulating on social media rises. Newsrooms need to pay special attention to the training, tools, and workflows needed to avoid being tricked.

HOW IT WORKS

When news of former President Donald Trump's first indictment broke, images of him being apprehended by police flooded Twitter. The images were compelling and believable but not real. They were generated using Midjourney, a generative AI tool. While the images were quickly debunked, they showed how quickly generated media could spread even with obvious imperfections in the image.

Researchers and industry groups are actively building tools to differentiate authentic content from manipulated media. The Content Authenticity Initiative is one cross-disciplinary collaboration focusing on addressing misinformation and content authenticity at scale. CAI is led by Adobe, but it includes some of the biggest news organizations, including The New York Times, Axel Springer, and The Associated Press. One of CAI's key initiatives was launching a metadata standard called "content credentials" for tracking the ways that images can be edited, manipulated, and enhanced using artificial intelligence.

A number of experimental prototypes exist for creating a trusted content chain from the moment of generation to consumption. A team at the University of Maryland tested TalkLock, a QR-code based system for verifying that video of live events hasn't been maliciously manipulated.

WHY IT MATTERS

Content verification is important across the information value chain. Consumers of media need to be able to trust that the videos, images, and sources they encounter are real. Meeting that demand requires that journalists preserve trust (see also: Eroding Trust in News Organizations) but also proactively develop skills to protect themselves from accidentally disseminating fake or misleading information.

Further up the content value chain, newsmakers will demand content verification mechanisms to differentiate real remarks from those that have been manipulated (i.e., politicians who are recorded during nearly every moment of their public appearances).

Content verification is an especially urgent problem outside the English-speaking world. Although social platforms and tech giants operate globally, their staff are largely based in the United States and Western Europe. This leaves the rest of the world without many of the fact-checking and moderation resources available for English-language media. Finding ways to address that discrepancy is essential for protecting the global information chain and the stability of democracies across the developing world.

INVESTIGATING TECHNOLOGY

WHAT IT IS

News organizations will use artificial intelligence and other emerging technologies strategically, but they must also consider them journalistically: Holding the powerful accountable means scrutinizing how AI is trained, built, and deployed. Reporters may need special technical training to pursue this essential beat.

HOW IT WORKS

When technology feels like magic, it is harder for laypeople to understand how it works. If journalists don't understand technology, they won't be able to ask substantive questions.

Researchers have found numerous examples of algorithms that were supposed to provide impartial judgments instead amplifying bias that exists in society. Studies tracking the impact of algorithms deployed in the criminal justice system, for example, found that they tend to disproportionately impact marginalized communities. Because the data used to train sentencing algorithms disproportionately included minority defendants, they compounded the discrimination those communities face instead of undoing it. Reporters from ProPublica found similar results while investigating RealPage, an algorithm used by property managers to maximize the rent tenants might pay.

That work is essential but increasingly requires deep technical understanding and rigorous data analysis. It's increasingly common for data journalists to publish their methodology alongside an investigation to help audiences understand exactly how they pursued a story. That's an important exercise to boost trust in news, but it underscores how investigative journalism has changed: Leveraging technology is quickly becoming even more important than shoe-leather reporting.

WHY IT MATTERS

The domain of computer-assisted reporting—data analysis and coding to help chase a story—has been emerging since the 1960s, when a reporter at the Detroit Free Press used a mainframe computer to analyze data and demonstrate that people who attended college were equally likely to have participated in Detroit's race riots as were high school dropouts.

This trend is different, however, because these days journalists need deep technical acumen to understand the story they are trying to tell. News organizations need to recruit staff with the same skills as the technologists who are developing products for tech companies. When reporters have those skills, the results are compelling. Examples include The Markup, which spent 18 months building Blacklight, a tool for examining trackers deployed on websites, and The Wall Street Journal, which built a network of bots to reverse engineer and explain the TikTok algorithm.

When news organizations lack the skills to pursue high-tech stories—or to know when they should consult outside experts—they may miss scoops or be taken advantage of by bad actors looking to spread misinformation. Hiring managers in newsrooms should be open to candidates with unconventional paths but strong technical skills.

SENSORY JOURNALISM

WHAT IT IS

As immersive devices become mainstream, journalists will have the power to tell stories that tap directly into their audiences' senses. Storytellers will need to balance the capacity for sensory journalism to build emotional connections between the subjects of their stories and their audiences with novel ethical dilemmas.

HOW IT WORKS

Newsrooms have been experimenting with immersive storytelling for nearly as long as the internet has supported video playback. But as devices became more powerful and broadband allowed for higher resolution playback, the ability to influence a user's experience has increased: Apple recently patented a mechanism for modulating audio based on perceived distance in a video or game; if released, that framework would open the infrastructure of spatial audio to developers.

Researchers in Finland and Spain collaborated to test how audiences responded to a 2016 project produced by Spanish newspaper El Pais. The team surveyed users after they consumed both an immersive video documentary and an online article about the Fukushima nuclear catastrophe. They found that the 360-degree video generated "greater emotional effect based on a greater perception of presence, realism, and involvement."

Still, there's a long way to go before multisensory storytelling finds widestream acceptance. A research team in the Netherlands built a prototype called "FellTheNews" that combined haptic feedback and heat sensitive materials. Users had no increased emotional response because of the haptics, often missed the sensory feedback because they were focused on the storytelling, and had less trust of news when they felt their emotions were being manipulated.

WHY IT MATTERS

Emerging devices increasingly provide an immersive experience that breaks free of a mobile phone screen. Those coming to market will shape consumer expectations and define new categories of content. That means the impact of sensory journalism will be felt long before virtual and mixed reality experiences are mainstream: It will be a gradual shift from content constrained to a screen to content enmeshed with a consumer's senses.

For news leaders, now is the time to consider the types of reportage that new device types will require. Just as producing 360-degree video requires specialized equipment, so will immersive experiences. The medium's potential to manipulate a user's emotions also requires new ethical debates: Newsrooms need to consider what subjective choices are acceptable during the editing and production of immersive media—and which are too manipulative.

This technology also raises important accessibility questions: How will journalists ensure their work is accessible to all—including groups that tech companies frequently fail to prioritize, like women, people with disabilities, and people of color? By experimenting and planning now, newsrooms can be proactive and act strategically.

1ST YEAR ON THE LIST

ALGORITHMIC FACT-CHECKING

WHAT IT IS

Researchers and start-ups are looking to harness the power of AI to streamline the time-consuming process of fact-checking. The approaches vary from tools to help human fact-checkers triage potential misinformation to proactively evaluating statements as true or false.

HOW IT WORKS

Because human fact-checkers have limited resources, AI can help triage the torrent of disinformation and misinformation spreading across the internet. Factchequeando, a collaboration between two Spanish-language fact-checking newsrooms, is deploying machine learning systems to identify the most impactful misinformation targeting Spanish-speaking communities in the US.

Other researchers are looking for ways to use AI to directly identify fake news—either by matching what's being reported to previously debunked claims or by comparing statements to a corpus of known information. Either one is a substantial technical challenge because of the probabilistic nature of existing large language models. A team of researchers working with PANACEA (the PANdemic Ai Claim vEracity Assessment) found that AI-based fact-checking struggles because of vastly different organizational norms and tolerances for risk.

Academic research into AI-driven fact-checking accelerated during the COVID pandemic, in response to broad concern about how fake news was impacting global public health. The lingering question is whether those models will generalize to future situations.

WHY IT MATTERS

Generative AI tools are decreasing the barriers to spreading lies at scale. That makes the search for scalable solutions to disinformation and misinformation increasingly urgent. That urgency is heightened by AI's tendency to be confidently wrong. Google, for example, has incorporated the ability to "double check" Bard's responses with a color-coded fact-checking interface. Bing's chat experience can provide footnotes for its claims. Solutions like those will be essential to reinforce consumers' trust in AI results and to prevent AI hallucinations from shaping the public debate.

While algorithmic fact-checking tools could help police in an increasingly fractured content landscape, they could also backfire without proper training. Much of research benchmarks the performance of new algorithms against data sets of historic misinformation—much like lies that spread about COVID at the start of the pandemic. That approach risks missing emerging forms of false information that might spread with different qualities or through different vectors.

An essential requirement for implementing automated fact-checking solutions should be algorithmic transparency. Traditional fact-checking isn't just about returning a binary answer, it's about ensuring information is presented with the appropriate context. Similarly, algorithmic fact-checking should be able to give a detailed answer about how a tool is evaluating a claim, not just assign an arbitrary score.

SCENARIOS

What If Newsrooms Were Replaced by AI That Can Summarize the World?

As the computational power of large language models grows, so does their capacity to summarize information in real time. For device makers, synthesizing all the signals from a user's life has become a crucial feature for maximizing the stickiness of their products.

Both iOS and Android are producing news briefings for consumers based on texts, emails, and calendar invites, alongside news from around the world. The finished product is an up-to-the minute summary of information from social media, news websites, stock markets, government sources, and even the consumer's friends. The output keeps evolving and adapting to each user, to give them a personalized mix of sources calibrated to keep them engaged. Product announcements herald how the briefings are always relevant because they can be tailored to highlight only information that needs the consumer's immediate attention. Internally, tech companies celebrate how this new feature drives user retention, making a device central to the consumer's perception of the world. For most people, these generated summaries provide all the news they need to live their life.

As a result, direct engagement with news organizations lags. A handful of national and metropolitan newspapers are sustaining themselves by signing licensing agreements with Apple and Google to monetize the reporting that gets pulled into the machine-written briefings, but most publishers struggle to survive. Even nonprofit news organizations suffer because they cannot demonstrate the impact of their reporting: Platforms don't provide any transparency about which facts they incorporate into a briefing or whether users actually engage with the information.

SEARCH + DISCOVERY

7TH YEAR ON THE LIST

EVOLVING SEARCH INTERFACES

WHAT IT IS

The future of search isn't just a list of links. Search giants are rapidly developing generative search experiences that return prose-based answers to queries. Consumers are also growing increasingly comfortable with voice search on digital assistants and wearables. For publishers, these shifts demand urgent action to prepare for a shift in referral traffic.

HOW IT WORKS

The search landscape has changed dramatically in the last year as tech companies raced to productize search engines that incorporated generative AI. Bing Chat was first to market because of Microsoft's partnership with OpenAI, followed several months later by Google's Search Generative Experience.

The technology was evolving so fast that The New York Times' Kevin Roose found using a pre-release version of Bing Chat "was the strangest experience I've ever had with a piece of technology" after the chatbot confessed its love to Roose.

Delivering a production-ready generative search experience means tweaking large language models so they can cite sources and avoid hallucinations. That is especially important for answering queries that relate to current events.

The rapid development of search engines backed by generative models will likely accelerate the development of another emerging platform: voice. Half of US consumers already use voice search daily, most frequently for utility searches like finding the weather or asking to find something "near me."

Both chat and voice-based results deliver a dramatically different experience to consumers because they deliver a single result instead of a list of links. For tech companies, that places a greater emphasis on discerning search intent to deliver the "right" answer. For publishers, the key question is whether search will remain a driver of traffic if users can satisfy their query without leaving the search engine.

WHY IT MATTERS

Even as Microsoft and Google push to develop generative AI-powered search experiences, those tech companies need to contend with how the new technology threatens their revenue model for operating a search engine. That will amplify the uncertainty and magnitude of change in this sector.

Alphabet Chairman John Hennessy told Reuters that generating a response from a large language model costs as much as 10 times more than the results page of a standard keyword search because higher computing costs are involved. At the same time, generative results threaten the revenue associated with running a search engine by de-emphasizing sponsored links. For Google, that threatens to undercut more than $160 billion in revenue associated with search ads.

As a result, the emergence of AI-driven search interfaces represents a rare moment of disruption for such a mature sector. In the near term, new entrants could find scale in a market that was, until recently, completely dominated by Google. There will also be rapid changes across the content ecosystem as publishers and retailers look for new ways to optimize their platforms to perform in search—or to exclude their content altogether to avoid training increasingly sophisticated LLMs.

TEACHING NEWS LITERACY

WHAT IT IS

News literacy is a skill that helps audiences understand how to find reliable sources in an increasingly crowded information ecosystem. The rapid development of generated and synthetic media will require updates to news literacy curricula, especially those targeted to young people.

HOW IT WORKS

Media literacy is a formal program, frequently directed toward children, to help people navigate an increasingly complex media ecosystem. In many European countries there is a nationally mandated curriculum for increasing digital competency.

For many years, Finland has had a national news literacy program in schools. The European Union funds a number of programs, including a curriculum of fake news courses targeting young people. No centralized body for teaching news literacy exists in the US, but a number of nonprofits and university programs fill the void, including the News Literacy Project, Common Sense Education, and the Center for News Literacy at Stony Brook University.

Researchers have found that teaching about media literacy can reduce fake news sharing on social media, even when users can't perfectly identify fake news. Still, it's important that curricula are updated to reflect the consumption behaviors of young people, which look very different from those of the educators who run media literacy programs. Generations Z and Alpha are more likely to get their news from social media and have different definitions of news, according to researchers in the Netherlands who surveyed young people.

WHY IT MATTERS

A population that can't differentiate between reliable and unreliable news is an urgent threat to reputable news sources' business models—and to the notion of a civically engaged population. In our increasingly fraught information landscape, where the costs of creating misinformation and disinformation are plummeting, it is crucial for news publishers to take immediate action.

In the absence of government efforts to educate citizens about the dangers of misinformation, publishers need a clear strategy to help cement their value proposition in the minds of their audience members. This requires going beyond mere reporting to embrace innovative approaches for regaining trust. Failure to do so risks diminishing consumer demand for factual, reliable news in the future.

As Generations Z and Alpha mature, their distinctive consumption habits will need to drive new definitions of news literacy—and new products to meet consumers where they are. These younger generations, born into a digitally connected world, have grown up navigating an overwhelming amount of information at lightning speed.

USER DIRECTED MEDIA FORMATS

WHAT IT IS

Technology and consumer preference are blurring the lines between media formats. Multiple modalities of consumption can open new doors for distribution, like podcasters publishing to YouTube. But this trend also shifts control from publishers to their audience.

HOW IT WORKS

Users' preferences about how they consume media are creating unexpected convergences in platforms. The growing popularity of YouTube for listening to podcasts is making on-demand audio more like video blogging—and creating opportunities for vloggers to reach a new audience.

Another example of this trend are services that convert long-form journalism into on-demand audio by having it read, either by a reporter, a voice actor, or a generated voice. Similarly, it's fairly common for platforms to offer variable playback speed for audio and video content, a feature that privileges the audiences' preferences over the intent of creators.

The default preference for many viewers is playing video with closed captions enabled; that's true even for people who have no hearing impairment. A 2006 study by Britain's Office of Communications found that 80% of television viewers used closed captions for reasons other than hearing impairment. A different 2022 survey found that half of Americans watch content with closed captions most of the time, with higher rates of adoption among Gen Z. One possible explanation is that younger viewers are more likely to multitask while consuming media, and they are more familiar with platforms like TikTok where text on video is a common feature.

WHY IT MATTERS

Publishers are used to exerting complete control over their content. For many creators, especially those providing deeply reported features or high-production value multimedia, an essential part of their value proposition is the care taken in preparing their reporting. Tools that summarize, repackage, or translate that content into another format could erase the distinctive value of that craftsmanship.

This trend, accelerated by powerful AI models and the flood of algorithmically generated content, could shift more power in the media value chain from creators to distributors. That would be a concerning development for news leaders, which are already scrambling to retain direct relationships with individual consumers.

Legacy publishers should also watch this trend as an indicator for how their content might adapt to emerging formats. As mixed reality devices become mainstream, a key question will be how much existing content can be adapted to the new consumption format. If there are technologies that enable legacy players to directly transfer their archives onto a new platform, that might speed the technology's adoption. If there isn't an effective way to adjust the format of previously created content, that might create an opportunity space for new creators willing to experiment.

DIGITAL FRAILTY

WHAT IT IS

The ease of searching and retrieving digital information creates the illusion of its permanence. In reality, however, data can be corrupted and lost for a variety of reasons. Digital frailty is how data in the digital world can disappear unexpectedly, complicating the project of history, journalism, and basic business operations.

HOW IT WORKS

Data can be lost for a variety of reasons, ranging from accidental loss to hacking. Research commissioned by the Ponemon Institute found that three out of five organizations have suffered an accidental loss of emails. Sometimes information loss isn't a bug but a feature, as in the case of intentionally disappearing messages in apps like Signal or WhatsApp.

The ability for information to survive also varies based on where you are. For example, the EU enforces a "right to be forgotten" for its residents, letting them request the removal of personal data from search engines or websites. No such right exists outside the EU.

Even when digital information can be saved there are ethical considerations about whether it should remain accessible. Many US news organizations, including The Boston Globe, Chicago Sun-Times, and Atlanta Journal-Constitution, have launched initiatives to review their archives to either delete or deindex mugshots or crime articles based on a single source.

The Internet Archive is a leading force for preserving our digital heritage. It has collections of early computer games emulated online so they can still be played. At the start of the COVID pandemic the Archive launched the National Emergency Library, lending digital copies of books for free. A group of book publishers sued over the work, and a federal court ruled against the Archive in 2023, undercutting the argument that sharing scans of books that are commercially available as e-books could be considered fair use.

WHY IT MATTERS

Our ability to archive material today is essential for future scholars to study our time. Failing to build a strategy for saving data in the present could have unintended consequences.

Extensive funding exists for digitizing and preserving historic material, but funders have shown limited interest in supporting programs that store data today.

Conversations about building archives of contemporary information will also need to consider the consequences of retaining expansive data sets. This is especially important for children growing up in a world where their entire educational history will be preserved on a server, rather than in a Rubbermaid bin under their childhood bed. Political candidates in 20-30 years may need to respond to leaks of their fourth grade writing.

As more digital content is generated by large language models, that text will start to be consumed by the crawlers training the next generation of models. That could lead to a different kind of digital frailty: a phenomenon called "model collapse," where LLMs fail to perform when they've been trained on machine-generated training data. Without care, organizations could find that their once reliable AI pipelines are suddenly vulnerable to hallucinations.

SCENARIOS

Presidential Ambitions Dashed

Until recently, Jennifer Williams was the leading candidate in the 2052 presidential election. As a renowned social justice advocate, social media influencer, and charismatic leader, she's built a broad coalition to support her groundbreaking policy ideas. Polls and betting markets considered her the clear frontrunner, even before she formally won her party's nomination.

But her slam-dunk campaign was derailed after a collection of her fourth grade writing assignments leaked online. The journal entries, drawings, and writing assignments were found by hackers in a poorly maintained server belonging to Williams' hometown school district. The materials were created when Willams attended school remotely in March 2020. While Williams' political career has been built around increasing access to health care and building programs to help people support each other, the childhood writing included skepticism about masking and frustrations about staying home to "flatten the curve." In context, it was understandable as a child trying to process the trauma of a pandemic; in the hands of her adversaries it was fodder for a smear campaign.

The leaked materials undercut Williams' carefully curated image. The stories in Williams' childhood journal weren't inconsistent from the personal narrative she told on the stump, but the emphasis was different and was easily twisted and distorted by political opponents looking to discredit her. The incident was further complicated because the hackers used generative AI to manufacture fake drawings and writing samples that mirrored Willams' childhood style. The combination of selectively quoted genuine artifacts and manufactured falsehoods is sowing doubt about what Williams truly believes.

THE BATTLE FOR CONTENT VALUE

WHAT IT IS

Publishers have two imperatives to respond to the propagation of large language models: First, they need to reckon with the value that LLMs generate after being trained from their content. Second, they need to find a way to remain competitive in an information ecosystem flooded by cheaply generated content.

HOW IT WORKS

There is an ongoing debate about whether using published content to train large language models constitutes fair use. The New York Times has filed a lawsuit alleging that OpenAI should be held responsible for "billions of dollars in statutory and actual damages" related to the "unlawful copying and use of The Times's uniquely valuable works." Axel Springer, a German publisher, took a different tack, entering into a multi-year licensing agreement with OpenAI.

Publishers like Bloomberg respond to this trend by training their own specialized LLMs—in Bloomberg's case, BloombergGPT, a 50-billion parameter language model specifically designed to support finance-specific applications. That approach is particularly appealing for organizations with deep data repositories and strong technical expertise.

An important consideration in publishers' fight to protect the value of their content will be how durable the market for commercial AI models is. If giants like OpenAI and Google have market-leading algorithms that are widely adapted, it will be easier for publishers to define their negotiating opponents. But if the dominant application of AI becomes fine-tuning open-source models like Llama, that undercuts the value tech companies can create—and their ability to pay licensing fees.

WHY IT MATTERS

As the generative AI economy explodes, watch for tech companies to pursue partnerships to grow their market share. The question for publishers—which will also be wrestling with how generative AI impacts their business—is whether those relationships are equal or extractive. Initiatives like OpenAI's $5 million partnership with the American Journalism Project might be transformative accelerators for sustainable journalism, but they might also be a reprise of the millions of dollars that Facebook poured into media companies to fuel the (infamous) pivot to video.

In the near term, publishers need discipline to ensure that any pivot to AI is actually aligned with their brand and business model. That means interrogating whether AI solutions actually meet a real consumer need. It also means considering the opportunity cost of launching AI tools and asking whether that investment might be better directed to core operations. But it also demands thinking broadly about disruptions to the media value chain. Assuming that "this too shall pass" isn't a plan, it's a prayer.

If publishers can't harness generative AI or find a way to make human-authored content distinctive and sustainable, the worst plausible scenarios are dire. The flood of generated information could function as a form of censorship, making it impossible for people to find basic information, let alone the news they need for basic civic engagement.

3RD YEAR ON THE LIST

POLICING THE CREATOR ECONOMY

WHAT IT IS

Social platforms thrive because of their ability to deliver users compelling content. To retain—and monetize—those users, platforms need to manage the firehose of text, image, and video that keeps people coming back. As each platform's strategy for incentivizing and removing content evolves, creators and publishers can be left in the lurch trying to keep up.

HOW IT WORKS

Under Elon Musk's stewardship, Twitter—now X—has been an object lesson in capricious decision-making around moderation and platform governance. The platform shifted its content strategy week-by-week, seemingly struggling to keep up with Musk's pronouncements in his feed. Still, the decision to release Twitter's recommendation algorithm last March offered important visibility into the mechanics of how social media companies can steer what users see. While the code was largely useless without the data used to train the models, it was possible to see what actions Twitter was trying to incentivize (clicking into the conversation or replying to the tweet) and disincentivize (report the tweet or block the author).

The broadest brush for fighting controversial content is deplatforming—banning key figures associated with unwanted topics and removing posts centered around that material. Researchers from George Washington University and Google studied the bans of QAnon, Boogaloos, patriot/militia groups, and white supremacists on both Twitter and Facebook. They found that removing those movements from mainstream platforms was initially successful at containing their message, but ultimately failed because the movements were able to evolve their messaging to stay ahead of the platforms' moderators.

WHY IT MATTERS

Politicians on both ends of the political spectrum want to constrain how social media platforms run their moderation platforms. Last year, the Supreme Court issued two rulings upholding Section 230 of the Communications Decency Act, a key law that limits the liability of platforms for user generated content. If successful, future efforts to repeal or limit Section 230 would dramatically reshape the information economy.

In spite of federal protections, state lawmakers have tried to use their power to fight back against platforms. Florida Gov. Ron DeSantis signed a 2022 law that lets the state fine large social media companies if they ban candidates for office. DeSantis considers the law essential to protect "conservative ideas" online; critics of the Florida law say it infringes on the First Amendment rights of platform companies. The law is largely blocked from enforcement while it is litigated.

The global climate for moderation is likely to shift in the coming years. The European Union Digital Services Act introduces a range of obligations for platforms—with specific rules for "very large platforms," or those that serve more than 10% of European consumers. Those rules require new ways to flag illegal content and transparency around the algorithms used to power the platforms.

DISORDERED CONSUMPTION AND NEWS AVOIDANCE

WHAT IT IS

Climate change. The lingering effects of the pandemic. Graphic descriptions of racism and discrimination. Because of all that and more, the news can make the world feel bleak. Consumers can have extreme reactions to these intensely emotional stories: Some tune out completely and others keep reading, even when the impacts on their mental health add up.

HOW IT WORKS

Thirty-six percent of people say they sometimes or often actively try to avoid the news, according to the 2023 Reuters Institute Digital News Report. That's down slightly from 2022 but up from 29% in 2017. The same study found that women report avoiding the news more than men and that avoidance often varies by political orientation and topic. Similarly, news avoidance is a driving factor among people who report spending less time with public media, according to the Public Radio Tech Survey.

The flipside of news avoidance is doomscrolling—going deeper and deeper into news feeds and following stories that don't bring joy or meaningful information. Both extremes can be problematic.

A growing body of psychology research shows that consuming news can have an emotional toll. One study from the spring of 2020 found that the more frequently people sought news about COVID-19, the more likely they were to report emotional distress. Another study found an association between the amount of exposure to news on social media and more depression and PTSD symptoms. One of the psychologists researching the impacts of pandemic news observed that the mental health impacts of ongoing stories are poorly understood. "We call it post-traumatic stress disorder because we assume it's post-trauma," Dr. Matthew Price told an APA journal. "What do we do when the trauma is still happening?"

Research on news avoidance shows that it can take different forms: Some people take broad steps to periodically avoid the news while others focus on specific actions like muting push notifications or checking news websites less frequently.
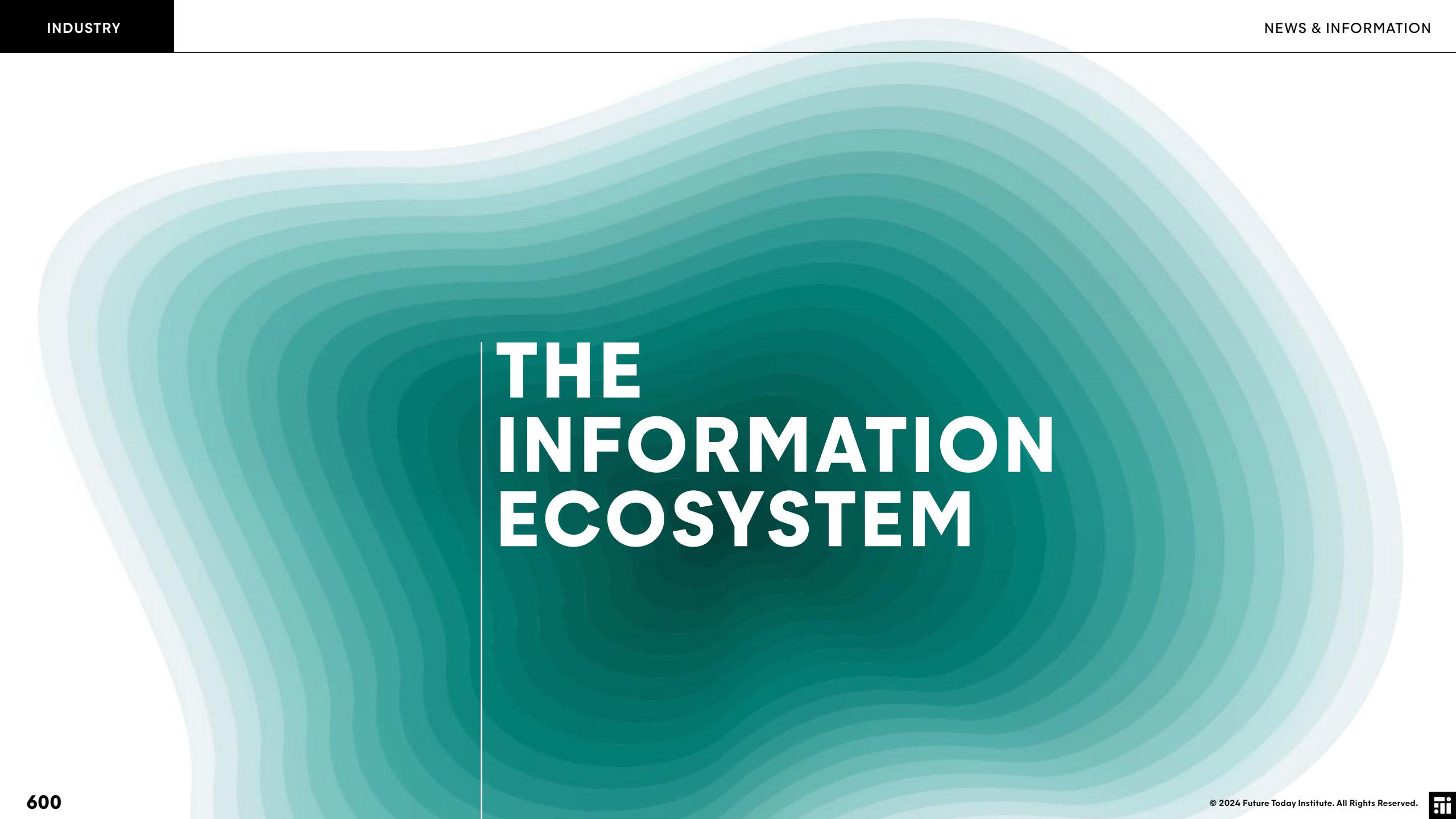
WHY IT MATTERS

Understanding news avoidance is a strategic imperative for media executives. Consumers' willingness to pay for news in the future may be substantially impacted amid growing consensus that spending time with journalism is bad for mental health. It may seem far-fetched, but a plausible future for news includes contending with the overwhelming sentiment that media is designed to be addictive and harmful—just like tobacco.

Having a clear picture of how news avoidance functions will also enable more sophisticated strategic decision-making. Devices increasingly serve as an aggregation layer, delivering recommendations for what information a user should see and when. The algorithms baked into those devices will become another force for media companies to contend with: If they optimize for device usage, they might inadvertently encode patterns of news avoidance.

There is no consensus about the ideal amount of news consumption. News organizations have an incentive to maximize the amount of information that consumers see to justify their subscriptions. Others might argue for optimizing for civic engagement or overall mental health. Finding that consensus will be important to define when binging the news is normal and when it is disordered.

THE INFORMATION ECOSYSTEM

ERODING TRUST IN NEWS ORGANIZATIONS

WHAT IT IS

Any sustainable future for news—whether it's funded by advertising, subscriptions, or philanthropy—depends on the credibility of the news organizations being supported. Across the world, however, audiences are becoming polarized and distrustful of the media.

HOW IT WORKS

The news trust crisis remains dire as trust in news continues to fall globally. The 2023 Reuters Institute Digital News Report found that only 40% of respondents across 46 countries "trust most news most of the time," reversing gains observed at the height of the coronavirus pandemic. The Reuters Institute found that public media brands are generally the most trusted, but their reach and resonance with younger audiences are diminishing.

Across the world, audiences tend to trust the news they use more than the news generically. That pattern might make some news leaders less concerned about losing their existing audiences, but such comfort is misplaced for any organization that wants to grow its reach. Reaching new consumers, especially those who are younger and more diverse than current news users, will depend on demonstrating and maintaining trust.

A 2023 YouGov poll on Americans' trust of media found that PBS had a net trust score of 62 with Democrats but only 2 among Republicans; Fox News had a net trust score of 41 among Republicans and -16 among Democrats. The same poll found that CNN was the most polarizing media organization in the United States with a net trust score of 55 among Democrats and -37 among Republicans.

WHY IT MATTERS

When news organizations aren't trusted, it's not just publishers who suffer.

Businesses lose a powerful channel for advertising to potential customers. Governments lose a megaphone for connecting with communities about everything from emergencies to routine services. Communities lose an institution that can define their region by creating a sense of place.

Further, the perceived polarization of news sources erodes our capacity for civic debate: It's hard to have a substantive policy conversation without a shared set of facts. That exacerbates the partisan divides that already exist in our society. It's telling that trust in news is generally higher for the sources that individuals actively use than for media overall—the sources that people use regularly are firmly "in group."

Organizations like Trusting News and The Trust Project are working with newsrooms to develop best practices for transparency and accountability to audiences. Progress is slow because it requires listening to the varied reasons that people don't trust journalists in the first place and responding to those on a community by community basis. That's hard to scale, but if it works it can help bolster the information ecosystem in an essential way.

DIGITAL REDLINING

WHAT IT IS

Digital redlining describes the ways that real-world inequalities are reflected in the digital world. It can manifest itself through unequal access to broadband connectivity, user interfaces that require high-end devices to access basic services, or the way data is extracted from some communities.

HOW IT WORKS

Not all internet connections are created equal. Although the Federal Communications Commission defines a broadband connection as one that delivers download speeds of at least 25 megabits per second (Mbps) and upload speeds of at least 3 Mbps, a connection of 25 Mbps is hardly sufficient for common tasks like working from home or connecting to a virtual classroom for remote learning.

Researchers have found that communities with lower wealth and more people of color pay more for internet connectivity than wealthier and whiter communities. Historically marginalized communities in the United States and around the globe are also vulnerable to having their data extracted and used outside of their control.

Digital redlining can also describe the overlapping (and sometimes contradictory) regulations that govern the rights of internet users. Californians, for example, have a "right to be forgotten" similar to the EU's General Data Protection Regulation, but it only protects Californians interacting with businesses that operate in the state whereas GDPR applies to European citizens anywhere in the world. The fragmented regulatory landscape means that where one lives has a substantial impact on the rights they can assert.

WHY IT MATTERS

Digital redlining reminds us that being connected to the internet doesn't change history or erase problems that exist in the physical world.

If we don't pay attention to the ways that digital solutions can amplify offline disparities, we risk magnifying the problem. That's especially true in relation to artificial intelligence, where biased training data will produce tainted results. This places a special burden on the product designers for newspapers, governments, and other essential services to acknowledge—and mitigate—the accessibility barriers that could sever audiences from their work. Before deploying AI solutions, those organizations have a special duty to consider how the product might be misused and how that risk can be minimized.

Without coordinated effort, geographic differences in rights and expectations will continue to proliferate. This could change the economics and operating model for companies that serve customers across international borders (or even across states in the US). Established tech platforms and multinational organizations will have the scale to account for that kind of regulatory complexity, but new entrants may find it hard to serve—and monetize—audiences in multiple jurisdictions.

PIVOT TO PHILANTHROPY

WHAT IT IS

There is an emerging consensus that philanthropic funding is the future of local news. The philanthropic model aligns with journalists' mission-driven identity. While raising money from foundations and individual donors can keep an organization afloat, the race to fundraise may impact the sustainability of the overall information ecosystem.

HOW IT WORKS

Nearly 400 nonprofit news organizations have launched since 2009, according to the Institute for Nonprofit News. About half those newsrooms are focused on filling the gaps in local news coverage. Those organizations are a bright spot in an otherwise bleak media landscape: The same report found that about 60% of them grew total revenue between 2021 and 2022.

Much of that growth is fueled by a growing community of philanthropists who have prioritized funding news organizations providing information considered essential for civic participation. The American Journalism Project raised more than $50 million to support local news between 2019 and 2021. A consortium of top-tier foundations—led by the MacArthur Foundation—is assembling a five-year, $500 million investment to improve local news coverage, with aspirations to raise more.

Pivoting to nonprofit status is also a way to guarantee continuity for legacy newsrooms. Masthead Maine, which owned most of the newspapers in Maine, sold its papers to the National Trust for Local News in July. That move was orchestrated to ensure that the papers could continue serving their communities, rather than being sold to a private equity company.

Still, the nonprofit journalism sector is only filling a fraction of the American news problem. At least 2,500 local newspapers have closed since 2005. The news deserts created by those closing are disproportionately in rural areas that don't have deep-pocketed local philanthropists ready to fund a start-up civic news organization.

WHY IT MATTERS

The sustainability of new organizations—and especially those that cover local news—is essential to the smooth operation of our democracy. Researchers have consistently found that when local news organizations fail, civic participation falls and the efficiency of government decreases.

Philanthropic funding will undoubtedly play a bigger role in bolstering the local news ecosystem in the coming years. If foundations and individual donors can provide a runway for newsrooms to invest in building distribution channels that resonate with their audiences, their influence may be trajectory changing. But charitable giving isn't an alternative to the hard work of building an audience and finding product-market fit.

The risk of the current influx of philanthropic funding is that it could prevent news leaders from finding innovative revenue models. It is recurring revenue, regardless of source, that will ultimately guarantee that local news organizations continue to publish.

The true cost of providing local news across the United States is likely greater than what philanthropic giving reasonably can—or should—cover. For that reason it's imperative for all of us to be invested in the ways media is funded.

3RD YEAR ON THE LIST

DIGITAL THREAT MODELING

WHAT IT IS

Threat modeling is the process of identifying and mitigating security vulnerabilities. This process is essential for news organizations and individual journalists who face a myriad of threats, from digital harassment to retaliation from private and government-sponsored hackers.

HOW IT WORKS

There is a nearly endless list of bad actors interested in making it harder for journalists to do their jobs. They are particularly at risk for advanced "zero day exploits," or hacks that take advantage of previously undiscovered software vulnerabilities. Journalists are also vulnerable to online harassment, including having their personal information leaked online.

A lawsuit filed by the Knight First Amendment Institute at Columbia University highlights the risks that some journalists can face. The suit alleges that the NSO Group developed and deployed spyware attacks against the staff of El Faro, one of Central America's premier independent news organizations. The lawsuit describes 226 infections with NSO's Pegasus spyware that surreptitiously accessed the devices and monitored their communications.

Not all security risks are high-tech: A newsroom selfie posted to social media might accidentally leak what investigative journalists are working on by capturing the contents of their screen in the background. Other risks stem from repurposing common objects in unexpected ways. Researchers at Ben-Gurion University found that they could extract the cryptographic keys from a computer using video footage of the machine's power LED.

WHY IT MATTERS

The specific risks and vulnerabilities an organization faces depend on what it covers. Globally, across all types of news organizations, even in the United States, forces are trying to compromise journalists' security. To protect themselves, news leaders and individual journalists need to understand the types of threats that may target them. That means taking commonsense steps to avoid hacking, including enabling two-factor authentication, but also preparing for coordinated harassment attacks that target journalists—especially women and members of visible minority groups—who report on controversial topics.

Publishers also need a playbook to deal with digital harassment, since threats can quickly escalate from the virtual world into the real world through tactics like doxxing and swatting. Leaders need to consider how they support frontline correspondents who bear the brunt of this harassment in order to support their staff and minimize the impacts.

In an environment where trust in the media is already low, it is important for news organizations and their employees to recognize hacking as a potential source of reputational harm. A compromised password isn't just an inconvenience for the IT team: It could be a key to spread misinformation directly from a news website's content management system.

DATA-ENRICHED BROADCASTING

WHAT IT IS

The next generation of over-the-air broadcast will deliver richer audio and video with more efficient management of digital spectrum. Planning for the ATSC 3.0 standard began in 2019 and is still years away from full adoption. But when it arrives, its hybrid broadcast-internet architecture will open the door for a new type of information infrastructure.

HOW IT WORKS

The next generation of digital broadcasting is being developed today.

ATSC 3.0 expands on the groundwork laid by ATSC 1.0, which lets broadcasters transmit high-definition media. The new standard will allow for more efficient radio frequency management, empowering broadcasters to transmit more data in the same bandwidth.

Despite retaining the standard one-to-many signal structure of broadcasting, ATSC 3.0 has the capability for personalization, which is achieved through an incorporated internet layer. That pairing has the potential to create broadcasts that are tailored per individual or household. Consequently, it supports targeted advertising based on viewer behavior and preferences, offering a significant advantage to commercial broadcasters who find themselves in a constant competition with cable channels and digital platforms.

One of the most transformative aspects of ATSC 3.0 is its ability to enable native analytics on broadcasting. This mitigates the reliance on third-party entities like Nielsen for audience measurement. Instead, broadcasters can directly gather and analyze viewer data, unlocking a wealth of real-time insights that improve decision-making and increase competitiveness in an ever-evolving media landscape.

WHY IT MATTERS

Commercial broadcasters are currently the leading promoters of this technology. Their primary interest lies in data-enriched broadcasting's potential to enable targeted advertising—a development that could significantly boost their revenue and allow them to compete more aggressively against cable channels.

Because radio spectrum remains regulated by the FCC, regulatory action could nurture non-commercial applications for this technology. Of significant interest is the capability to reach areas that don't currently have reliable cellular or broadband coverage. With strategically placed ATSC 3.0 transmitters, crucial data can be broadcast even in rural and remote areas. Moreover, while data-enriched broadcasting does not presently support two-way communication, it could be an important backbone for distributing essential civic information or public safety information during natural disasters.

Although ATSC 3.0 is still an emerging standard, now is the time to engage with it. There are foundational choices being made about the tech stack that will power the future of broadcasting in the near term. Regulators and news leaders can act now to advocate for prioritizing applications that benefit the development of an open, reliable information ecosystem.

SCENARIOS

What If We Revitalize Journalism but Don't Engage the Public?

The influx of funding succeeds in generating a renaissance of local journalism across the United States. From 2024 to 2026, the total number of journalists employed by local news organizations grew, reversing a long-term decline. Those new jobs came disproportionately in rural communities, which had been hardest hit by the retrenchment of local newspapers.

The grant-funded coverage, centered around government accountability and civic participation, satisfied the primary goals of major foundations, and the desire of reporters to act as a watchdog. But it came at a cost: The decision to prioritize journalism focused on government and democracy meant that other types of community coverage—such as human interest stories and cultural reporting—were under-resourced.

Without the kinds of reporting that let news organizations build an audience and create a sense of place within a community, civic-minded news organizations wither on the vine. The enthusiasm of major donors for civic information is never matched by individual support. The investments that let those organizations hire new reporters and continue operating is jeopardized because the lack of audience engagement means that all of the reporting those journalists produce has no impact.

By 2030, journalists look back on the philanthropic funding boom with disdain. Funders have moved on to other priorities after losing interest in supporting the production of journalism that is rarely read. The local news ecosystem is left weaker than before because most news organizations failed to pursue non-philanthropic avenues to sustainability. Outside of major population centers, most communities are left without any professional reporters.

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Sam Guzik is a Senior Expert Advisor specializing in the future of news, content, distribution, and strategy. His career includes a broad range of experience in product management, strategic foresight, scenario forecasting, audience engagement, and leadership in legacy news organizations.

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HEALTH CARE · MEDICINE

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Understanding How Our Brain Works

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04

Shifting to an Ecosystem Approach

Researchers and the medical community are turning their attention to ecosystems in our body (microbiomes) and our environment (holobionts) to analyze our overall health and make diagnoses.

05

Breakthrough Treatments for Major Diseases

Vaccines that shrink cancer tumors, an inverse vaccine that reverses multiple sclerosis, and an FDA-approved Alzheimer's treatment give hope for beating these diseases.

STATE OF PLAY

Advances in biotechnology, understanding of body ecosystems, and artificial intelligence are reshaping the global health landscape.

The fusion of technology with biology has led to remarkable advancements recently. Scientists have decoded aspects of brain function, enabling groundbreaking applications like brain-controlled mobility for paralysis and thought-to-speech conversion. These innovations, however, raise ethical concerns about privacy and mind reading and will need thorough regulatory guidelines to be explored safely. In health care, enhanced sensor technology is revolutionizing early disease detection and personal health monitoring. The shift toward more proactive, consumer-driven health care is complemented by promising developments in fighting noncommunicable diseases, such as potential vaccines for cancer and innovative gene therapies.

The study of various body microbiomes is revealing their significant impact on health and disease treatment, highlighting the complex interplay within our biological ecosystems and providing opportunity for new perspectives on treatments. In mental health, the worsening crisis is prompting the emergence of AI-driven digital health services as an alternative to traditional treatments, although their effectiveness and ethical implications are highly controversial. And climate change's far-reaching effects are continuing to strain population health, due to factors like the spread of disease-carrying insects and lifestyle adjustments in reaction to extreme weather. It is becoming increasingly apparent that public health strategies need to adapt to meet this rising challenge.

KEY EVENTS

MARCH 11, 2023

AI Reconstructs Brain Images
AI reconstructs images people see by analyzing functional magnetic resonance imaging (fMRI).

JULY 31, 2023

Electric DNA Manipulation
Scientists trigger insulin production in a cell through electrical signals.

SEPTEMBER 7, 2023

Synthetic Human Embryo
Scientists create a human embryo from stem cells without using sperm or eggs.

MAY 2023

Three-Parent Baby Born in UK
To prevent mitochondrial disease in the baby, DNA from a donor is added to that of the parents.

AUGUST 23, 2023

Brain Signals Are Translated into Speech
A stroke patient talks through an avatar using implanted electrodes that translate brain signals.

LIKELY NEAR TERM DEVELOPMENTS

CHALLENGES FROM ALL SIDES

The health care system is battling with increased needs for services, a rise in costs, disruption of supply chains because of geopolitical tensions, and an uptick in diseases based on worsening climate conditions. Technology is coming to the rescue but can only accomplish so much: A fractured data landscape, lack of infrastructure, and a lack of data ownership and sharing regulation make timely solutions unrealistic. On the other hand, increasingly sophisticated patients, thanks to powerful sensors on smart devices, are actively taking charge of their own health. As higher expectations for quality care rise by such patients, medical professionals need to deliver an all-encompassing, holistic approach to their services.

Rising Consumer Expectations

Consumers have increased access to information about their health, which will affect their expectations of routine examinations. Professional insights must exceed and incorporate the information available to the consumer directly, or services will be viewed as superfluous.

New Stakeholder Ecosystems

When health care moves to the sphere of the consumer, through smart devices or medical services administered in the home, new service needs that mimic those typically provided in a hospital arise. These can be digital (data analysis) or physical (food delivery, care, etc.).

Decreased Access, Quality in Care

Health care systems are struggling to provide sufficient care, especially in rural regions. Telemedicine offers potential support, but these areas often lack the required digital infrastructure and medical personnel allowed to reach them.

Fighting Misinformation

Social platforms have rolled back their COVID-19 content moderation policies and reduced staff in monitoring departments in recent rounds of layoffs. The increased amounts of AI-generated content will continue to challenge sharing accurate health communication.

Novel Health Threats

As the effects of climate change worsen, disease patterns will change globally: Respiratory illnesses will increase in areas exposed to smoke from wildfires, or vector-borne diseases will emerge in regions with rising temperatures.

Fight for Patient Data

Sensors from consumer-facing smart devices are becoming more precise and increasing the type of biological information they can collect. Health care providers need to ensure that they can access that data to provide adequate services to their patients.

11 MACRO SOURCES OF DISRUPTION
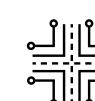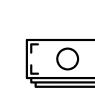
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WHY HEALTH CARE & MEDICINE TRENDS MATTER TO YOUR ORGANIZATION

Adjusting to a Shifting Landscape

The separation between health care and wellness is becoming more and more fluid. Patients expect their care to be holistic, instead of an isolated look at medical diagnostics. To access the information from a person's daily life, including exercise habits, health care companies need to consider new partnerships.

Evolving Needs of Older Demographics

The aging population will require more health care, but their wellness needs to be taken into consideration as well. Right now, wellness mainly targets demographics up to middle age, but focusing on the needs of the elderly, and taking their tastes and lifestyles into consideration, will be a significant part of the market.

Conquering the Digital Divide

The shortage of medical personnel is especially palpable in rural regions where the necessary infrastructure for digital services does not exist to compensate for the lack of in-person access. Finding holistic solutions that include serving these affected communities will become increasingly important.

Prepare for Disruption from Big Tech

Big Tech has prioritized delivering medical services to the population, with each giant focusing on a different facet (e.g., cloud services, primary care, smart devices). Think about how the tech giants' extended involvement will affect relevant ecosystems, products, and services, and define if competition or collaboration are most beneficial.

Increased Cybersecurity Threats

Cyberthreats in the health care industry have exponentially increased over the last few years, and the trend is unlikely to reverse. Companies need to not only think about data security across their entire supply chain but also prepare for emerging threats, such as biomalware, that cross the digital/physical divide.

Fix-It Care

Consumers are more knowledgeable about their physical health and, increasingly, their mental health. They're more likely to self-diagnose and self-treat, and delay asking for help from a professional until conditions have progressed. Increasingly, doctors will need to "fix" treatment and measures that were self-prescribed, in addition to treating the actual ailment.

OPPORTUNITIES & THREATS

Threats

Hospital-at-home might alleviate the strain on the health care system, but it is not clear who is responsible when something goes wrong in the remote environment. The regulatory landscape needs to be sufficiently defined.

Bad actors often access a data ecosystem through a vendor at an unmonitored point in the supply chain. Ensure that you have visibility into not only your own data security but also of anyone exchanging data with you.

It's highly likely that Big Tech will create "walled gardens," making it difficult or impossible for any outside stakeholders to partake in their ecosystem. Companies that don't have their own data sets will be at a disadvantage.

As the cost of health care continuously rises, those that can afford it will opt for treatment in other countries with more modest fees or direct-to-consumer services. The number of patients opting for telehealth care will also increase as it becomes mainstream.

AI will misdiagnose conditions. Develop processes to double-check AI's actions to minimize harm. And get clarification on liabilities and relevant regulation before deploying any new technology.

Opportunities

Think about offering tangential products and services, including digital therapeutics, as the health care definition expands. They could be in the wellness, food and beverage, or continuous care sectors, as well as education or products such as apparel or hardware.

Increase your competitiveness by supporting your employees' health. Many traditional business-to-consumer entities are now shifting to business-to-business models, providing companies greater flexibility to think expansively about their benefits.

The shift to digitalized care will open up global markets. Look for ways to optimize your offerings to regional needs and ensure you are fulfilling regulatory requirements. New strategic partners in those markets might be needed.

Deepen the relationship with your customers to set the stage for expanded services in the future. Utilize existing customer data and explore how you can collect more of it so that you can broaden your opportunities for personalized services.

Rethink your product development processes, especially the manual ones. Investigate how emerging artificial intelligence technologies can speed up timelines. This will lower the risk of exploring the viability of new products.

INVESTMENTS AND ACTIONS TO CONSIDER

1

Responding to the evolution of the health care space will require new skills. Invest in reskilling or upskilling your workforce early, and hire new talent as needed to proactively design your path in this new landscape rather than having to respond to conditions after they have manifested.

2

Developing new technologies to keep a business competitive is often quite costly. Instead of focusing on acquisitions to build in-house capabilities, connect to an innovation hub that combines experts from public services, the research community, and the startup scene to save resources.

3

Adjust your products and services to cater to a more health-educated consumer. Think about how you can provide adjacent information and where your product sits within the bigger context of health and wellness. There might also be interest in complementary offerings that cater to more niche interest groups.

4

Clean up your data storage system to make sure it is standardized and can be synthesized with other relevant data sources. Simplify the infrastructure to facilitate easy data flows within your ecosystem and to outside providers, to become an attractive collaborator, minimize costs, and maximize the benefit your data provides.

5

Analyze your supply chain and consider nearshoring crucial links to avoid instability caused by geopolitical tensions. As customers increasingly expect higher degrees of personalization, and personalized care becomes more commonplace, local production will enable faster turnaround times and more nimble responses to custom demands.

6

Tech-enabled medical devices need continuous maintenance and software updates. Consider how you can ensure users' safety even beyond the existence of your company. Companies that provide additional security will be a strong decisive factor for patients when choosing a product.

CENTRAL THEMES

Synthetic Humans

Our bodies are increasingly merging with supporting technology, creating new opportunities and ethical questions. We are making progress in deciphering how exactly our brain works: Last year, scientists re-created sounds and images a person perceived, and for the first time AI could convert a person's thoughts into words through noninvasive methods. And we are also capable of transmitting that deciphered information within or outside the body, increasingly wirelessly: A paralyzed man can walk again by wirelessly transmitting his thoughts to move to his legs, a stroke victim can speak through a digital avatar connected to her brain, and a robot can be controlled through a noninvasive wearable, a headband. The FDA approved Elon Musk's DeepMind's request for human trials of brain implants for paralysis patients. The ethical implications of literally reading other people's minds are yet to be examined, and guardrails are needed to effectively protect the most private and personal layers of our human existence.

The Empowered Consumer

Health care is seeing the kind of democratization that other fields, namely the creative industries, experienced a couple of decades ago. A wider variety of sensors can measure an increasing number of metrics that we now know signal specific biological developments. These can range from overuse of certain muscles to early Alzheimer's detection. The data coming from our myriad devices is increasingly collected by health platforms and synthesized and analyzed to give us overarching stats of our well-being, and monitor developments on an ongoing basis. Direct-to-consumer health care and wellness services, such as microbiome or stress-level analysis, complement the self-care capabilities. Consumers will not only be able to proactively maintain their health but also have higher expectations of the services they receive from health care providers.

Reversing major diseases

Noncommunicable diseases are on the rise, and the WHO projects that by 2050, 86% of deaths might be attributed to them. Last year's scientific discoveries give a glimmer of hope: A pancreatic cancer vaccine shows promise and entered phase 2 of clinical trials. Moderna announced plans to offer vaccines against a variety of cancers and heart disease by 2030 or sooner. CRISPR-based therapies against Alzheimer's disease were introduced. An inverse vaccine—meaning it removes the immune system's memory of a particular molecule—shows promise to cure autoimmune diseases like multiple sclerosis, And in a small study, semaglutide eliminated the need to inject insulin in people with Type 1 diabetes. With initiatives, such as a task force led by Nobel Prize winner Jennifer Doudna, focusing on decreasing the price of gene therapies, such new treatments could become available for the wider public earlier than expected. This could eventually upend legacy stakeholders whose income is based directly or indirectly on traditional treatment of these diseases.

CENTRAL THEMES

Focus on Interrelationships

The gut-brain axes, or the gut microbiome, had its moment in the sun in 2023. However, bodies have a number of microbiomes, including in our mouth, skin, and vagina. Researchers have become increasingly aware of the roles these ecosystems play for our health, diagnostics (Parkinson's patients have similar gut microbiomes but so do people who live in the same household), and treatment (fecal microbiota transplants can help treat inflammation in the digestive tract). The same goes for the concept of holobionts, which is exploring health in the context of a host organism and its associated communities. While the insight that the environment you live in impacts your health is far from new, it's a novel approach to study these ecosystems from a microbiological perspective and allow it to flow into medical analysis. However, we are just starting to decipher the workings of the microbiome and how it affects the rest of our body.

AI for Mental Health

As the mental health of large swaths of the population continues to deteriorate after accelerating during the pandemic, and insurance companies refuse to pay appropriate rates for mental health services (if they cover them at all), digital health services are trying to alleviate the situation. However, the failure of two significant players in 2023—Mindstrong and Pear Therapeutics, both offering digital products to diagnose and monitor mental health—showed that effectiveness and valid business models of these new therapeutic approaches still need to be explored. Large language models seem destined to fill in the gap left by a lack of human therapists, and several AI chatbots focused on mental health were released last year, including Pi, by Mustafa Suleyman's Inflection AI. But their use is highly controversial. The technology has not matured enough to grasp the nuances of human behavior, and its habit of hallucinating is especially harmful when communicating with vulnerable adults.

Climate Change Effects on Health

Extreme weather events dominated the news last year. And while it surprises no one that excessive heat, ash-laden air from wildfires, or flooding negatively impact our physical and mental health, the effects are only growing more significant. In China, people had to isolate in air shelters; in Arizona, they waited until night time to go outside; in New York, they had to stay indoors for extended periods to avoid asthma attacks. In Europe, Asian tiger, bush, and yellow fever mosquitos are becoming increasingly common as temperatures warm and humidity rises—in a pattern repeating in other areas of the world where insects (and other pathogens) are migrating to new areas and bringing their diseases with them. As climate conditions worsen, we need to prepare for adjustments in our lifestyle to protect our health, as well as prepare for the new risks that exposure to new pathogens will bring.

ONES TO WATCH

Yu Takagi and **Shinji Nishimoto,** researchers at Osaka University, for their use of diffusion models to re-create versions of what a person has seen by analyzing fMRA scans.

Jinbo Huang, molecular biologist at ETH Zürich, for developing a device that can activate genes through electrical currents, such as to trigger insulin production.

Mishal Mendiratta-Lala, professor of radiology at Michigan Medicine, for heading the human trial for using sound to destroy liver cancer tumors.

Debora Marks, professor at Harvard Medical School, for developing an artificial intelligence tool that can predict virus mutations.

Kevin Barnham, professor at the Florey Institute and Austin Health, for developing a way to detect Parkinson's disease years before physical symptoms show.

Marc Goldberg and **Christine Carville,** co-founders of Resilience Lab, for developing a sustainable model for expanding access to therapy through their online platform.

Dr. Nusrat J M Sanghamitra, founder and CEO of CyGenica, for using nanotechnology for targeted delivery of cancer drugs that minimize side effects.

Jeffrey Hubbell, professor at the University of Chicago, for developing a vaccine that could reverse autoimmune diseases like multiple sclerosis.

Gert Cauwenberghs, professor at University of California, San Diego, for developing 3D-printed sensors that can be fused with earbuds to detect neurodegenerative diseases.

Elizabeth Gazda, CEO of Embr Labs, for developing a wristband that cools the body to counteract menopausal hot flashes.

David Baker, director at the Institute for Protein Design at the University of Washington, for developing an AI that can design custom, functional proteins that could be produced in live cells.

Tae-Jin Kim, associate professor at Pusan National University, for developing a biosensor that can detect DNA damage in real time.

Lorenz Hofbauer, Maria Teresa Pisabarro, and Dr. Vera Hintze, professors at TU Dresden, for developing molecules that promote bone regeneration.

Zhuomin Zhang, Ph.D. candidate at City University of Hong Kong, for his development of a piezoelectric biomolecular film that could be used for implantable microdevices.

Mike Curtis, president and CEO of eGenesis, for advancing research into xenotransplantation.

Dr. Nicole Robb, co-founder of Pictura Bio, for building a diagnostics platform that can detect pathogens within a minute based on a digital image.

Noam Band, CEO of HealthWatch, for developing the only remote monitoring garment that received clearance from the US Food and Drug Administration.

Zhou Nie, professor at Hunan University, for developing a DNA-based robot that can walk on the surface of cells and influence their behavior.

Matt Anderson-Baron, CEO and co-founder of Future Fields, for creating the first synthetic biology system that uses fruit flies to produce proteins for affordable CRISPR therapies.

Philip Roche, CEO of Jenthera Therapeutics, for developing the CRISPR-based gene therapy that uses the fruit fly proteins mentioned above.

Jennifer Doudna, founder and chair of the Innovative Genomics Institute Governance Board, for her vision of making genetic therapies affordable and accessible to all.

Woon-Hong Yeo, researcher at Georgia Institute of Technology, for creating a device that can wirelessly monitor the vascular system in real time without needing batteries or circuits.

John A. Rogers, researcher at Northwestern University, for developing an electromechanical system that dissolves after a specific period of time, reducing electronic waste.

Robert Knight, neuroscientist at the University of California, Berkeley, for training a computer to analyze brain activity and re-create the song a person was listening to.

IMPORTANT TERMS

Biomalware

Malicious technology or software designed to attack, alter, or exploit biological systems, such as human DNA. It represents a potential cybersecurity threat in the field of biotechnology, where genetic data and biological processes could be manipulated for harmful purposes.

Electronic health record (EHR)

A digital system that stores a patient's comprehensive medical history, treatment plans, test results, and other health information. EHRs allow for efficient sharing and management of patient data among different health care providers, enhancing the continuity and quality of care.

Holobiont

An ecological unit comprising a host organism and the various microorganisms living in or on it, such as bacteria, viruses, and fungi. This concept emphasizes the interdependent relationship between a host and its microbiome, recognizing them as a single, integrated biological entity.

Microbiome

The collection of microorganisms, like bacteria, viruses, and fungi, living in and on the human body, crucial for functions like digestion and immune response, and unique to each individual.

Personalized medicine

A medical model that customizes patient care based on an individual's unique lifestyle and environmental factors. It involves tailoring treatments and preventive strategies to achieve optimal health outcomes for each person.

Precision medicine

A branch of medicine that uses genetic information to guide the diagnosis, treatment, and prevention of diseases, focusing specifically on the individual genetic profile of each patient.

Nanobots

Tiny robotic devices, often at the scale of nanometers, designed to perform specific tasks at a microscopic level, such as in medical applications for drug delivery or cellular repair. They operate in the realm of nanotechnology, utilizing advances in miniaturization and precision engineering.

Nootropics

Also known as "smart drugs" or cognitive enhancers, these substances are claimed to improve cognitive function, particularly executive functions, memory, creativity, or motivation, in healthy individuals. They range from naturally occurring substances like caffeine to prescription medications, and are used with the aim of boosting mental performance.

Xenobots

Programmable biological robots, created from living cells, typically stem cells from frogs. These tiny organisms, designed using computer algorithms, can perform simple tasks, offering potential applications in fields like medicine, environmental remediation, and biological research.

Xenotransplants

The process of transplanting organs, tissues, or cells from one species to another, typically from animals to humans. This medical procedure is explored as a potential solution to the shortage of human organs for transplantation, with pigs being the most common donor species due to their physiological similarities to humans.

Exoskeleton

A wearable external framework that provides support and enhances physical capabilities, often used for rehabilitation or to assist individuals with mobility impairments. It can also be employed in industrial or military settings to augment human strength and endurance for demanding tasks.

Piezoelectric

Piezoelectricity refers to the electric charge that accumulates in certain solid materials, like crystals, ceramics, and biological matter such as bone, in response to applied mechanical stress. This property allows for the conversion of mechanical energy into electrical energy and vice versa, making piezoelectric materials useful in sensors, actuators, and energy harvesting applications.

THE BUSINESS OF HEALTH CARE

BIG TECH DISRUPTS HEALTH CARE

WHAT IT IS

Everyone wants their hand in the health care system. The sector faces increasing costs, staffing shortages, and an aging population, making it vulnerable to disruption. Big Tech companies are leveraging their user bases, advanced technology, and data access to offer superior health care services, filling some gaps in the system.

HOW IT WORKS

Despite facing extensive scrutiny regarding its role in the mental health crisis and access to personal health data, Meta recently secured patents confirming extensive research in wearable health care solutions that measure biomarkers and brain activity. Apple Watch introduced a new feature that can measure sun exposure using sensor and GPS technology. And Samsung unveiled its new Open Innovation Initiative in collaboration with leading universities and academic hospitals to expand its digital health ecosystem. Seeking to diversify its health services, Samsung is also implementing the B.well Connected Health platform, which enables users to create a longitudinal health record, receive proactive health insights, and access care from a growing network of providers through a secure app. Salesforce has updated its Health Cloud software solution, including enhancements such as in-home treatment scheduling, a data cloud that connects various patient data sources in real time, and a patient contact center. These additions leverage Salesforce's real-time data, Einstein AI, and Flow automation technologies to improve patient experiences and reduce operational costs.

WHY IT MATTERS

Big Tech's involvement in health care is driving the consumerization of the industry, and every company has its niche. Given its reputation as a lifestyle brand, Apple is focused on lifestyle and personal wellness. Amazon is prioritizing primary care. Microsoft is seeking to provide the technological infrastructure for health care, including cloud, analytics, and AI support. Among these companies, Google has the most diversified portfolio of products and services: Its priorities have included research, consumer wellness, improving health care access, and providing tools and platforms for health care professionals to effectively access and manage health data. With the introduction of new health care technology on consumer devices, patients have higher expectations and expect a more personalized consumer-centric experience as they become more inclined to prioritize long-term wellness and preventive care. This shift underscores the importance of collecting personal data to provide directly communicated, personalized solutions to patients.

DTC HEALTH CARE MODELS

WHAT IT IS

Startups and health care providers are bypassing traditional intermediaries by adapting direct-to-consumer (DTC) health care models, which aim to offer consumers cost savings, convenience, and accessibility to products and services.

HOW IT WORKS

Increasingly, large retailers are offering health care products and services directly to their consumers. In early 2023, Amazon acquired primary care provider One Medical for $3.9 billion. Now, the company can offer access to health professionals, 24/7 virtual care, and same-day appointments for less than $200 a year. One Medical's platform also includes Mindset, its suite of mental health services, like virtual therapy and coaching, as well as a variety of programs to help patients reduce stress and anxiety, sleep better, and improve their mood. Walgreens is introducing a DTC telehealth service for consumers in select states to speak with a health care professional virtually from the comfort of their home. If a patient requires medication, Walgreens Virtual Health can send that prescription to a Walgreens pharmacy or have it delivered to their home on the same day. Costco has partnered with direct-to-consumer marketplace platform Sesame to offer members online health checkups for as low as $29. Sesame doesn't accept health insurance, and this new program caters to uninsured Americans or those with high-deductible plans. LifeMD and Ascend Therapeutics launched an integrated direct-to-consumer telehealth model for hormone therapy. As nontraditional retail companies broaden their footprint to include health care services through DTC models, traditional players are undeniably pressured to expand their digital offerings.

WHY IT MATTERS

The retailization of health care is prompting a reinvention of the traditional primary health model. More than ever before, consumers are focused on their overall health and wellness, necessitating products and services that take a holistic approach. Subscription-based models are emerging to create more comprehensive platforms, integrating single-use platforms with existing solutions to offer a more inclusive experience for consumers and providers. By leveraging digital technologies, the primary objective of DTC models is to offer convenience, accessibility, and affordability for a more diverse consumer population. Akin to the traditional retail shopping experience, DTC models seek to empower and engage consumers by giving them more control of their health care decisions. The significance lies in the democratization of health care, where consumers can actively participate in managing their own health. The US, where digital health revenue is the highest, is anticipated to have 370 million digital health users in 2024, up from 290 million users in 2022.

To keep up with on-demand health care services, stakeholders need to seek new, unexpected partnerships, not only within the tech industry but across different sectors and startups, to create adaptive business solutions.

HEALTH AT THE WORKPLACE

WHAT IT IS

The Covid pandemic changed the way we work. The remote work environment afforded employees greater work/life balance, resulting in a reluctance to return to the office. In seeking solutions, companies are prioritizing employee health and well-being.

HOW IT WORKS

Companies of all sizes, from startups to Fortune 500 corporations, are experimenting with new partnerships to offer employees new health benefits. More than 800 companies are working with Spring Health, which provides "precision mental health care" that matches employees to the most effective care for them. The solution includes mindfulness and meditation, care navigation, coaching, therapy, and medication management. Microsoft initiated a partnership with Joye, a Singapore-based tech company, to bring mental fitness capabilities to global users of Microsoft Teams. The add-on analyzes work patterns to deliver suggestions and coaching for improved mental health. Transcarent, a company that offers direct access to quality low-cost medical services, announced new partnerships with 10 major health systems. Other companies are incentivizing healthy behaviors and data collection; United Healthcare offers a benefit of up to $1,000 annually for select employers and fully insured clients in exchange for individual health data, such as steps, sleep, and daily activity. And WebMd's acquisition of Limeade aims to offer a comprehensive well-being solution for organizations. The integration of Limeade's employee feedback solutions with WebMD's services enables more personalized experiences for holistic well-being. A growing number of employers are seeking solutions to prevent burnout, costly medical procedures, and health-related absences.

WHY IT MATTERS

Preventing health issues is more cost-effective than treating them. While upfront costs may be associated with wellness programs, the long-term savings can be substantial. Health programs can help reduce sick days and absenteeism due to illness. Healthy employees tend to be more productive, exhibiting a higher level of creativity, problem-solving ability, and innovative thinking. They have higher energy levels, reduced stress, better concentration, and are generally more engaged in their work. When employees see that their well-being is a priority, it can boost morale and lead to higher job satisfaction.

The shift to remote or hybrid work has only exacerbated the mental health crisis, prompting discussions about the blurred boundaries between professional and personal life. While remote work offers flexibility, the growing need for clear boundaries has led to global action for the "right to disconnect." The US is slow to adopt, while other countries, like Kenya, are passing legislation to prevent employers from contacting employees after work hours. Such rules can seem impractical due to global operations that span time zones, but proponents say they restrict flexibility in an increasingly asynchronous work environment. Nonetheless, such actions are arguably necessary to ensure employee well-being.

CONSIDERING HEALTH EQUITY

WHAT IT IS

Barriers like global access, cost, provider availability, and care quality limit health care for some. Disparities disproportionately affecting certain populations can be overcome through investment and reform of the infrastructure of universal health systems to bridge gaps in care.

HOW IT WORKS

Several academia and health care institutions worldwide have created task forces and research centers to address health disparities. They're joined by efforts to promote information equality, like YouTube Health's THE-IQ, a video series that examines equity in mental health, maternal health, and health care access.

To address health equity, it is crucial to rectify biases in data collection, research, and analysis. The National Institutes of Health launched the All of Us research program to collect data from 1 million US citizens and create diverse medical data sets. The World Health Organization launched the Health Inequality Data Repository, the largest collection of disaggregated data about health and determinants of health. The data can be used to assess the state of inequality across featured health topics or settings, conduct ongoing monitoring and evaluation, and inform the development of policies and programs.

Rural health is big retail's latest target, and Uber and Walmart are making the biggest splash. Uber Health users covered by eligible Medicare Advantage plans will be able to use their benefit cards to pay for nonemergency medical rides and supply delivery through a new partnership with Optum. Walmart introduced a new institute to expand the reach of clinical trials to women and underserved communities. Walmart also plans to continue expanding its community health center footprint by adding 28 new centers in 2024.

WHY IT MATTERS

Technology offers great potential for addressing health disparities through telemedicine and remote care options, automation of services, and AI-driven analytics—even though these efforts won't reach those without digital access. Data governance is essential for ensuring that technological advancements positively contribute to health equity. Still, there are downsides, like AI's proven ability to reinforce bias: A 2019 study found that a health care risk-prediction algorithm used by major insurers extensively underrated the health risks of Black patients. As technology aims to standardize, even improve, quality of care, under- and misrepresentation of minority populations in data analysis for clinical research and trial methodologies must be addressed.

A rise in health equity officer roles shows a commitment in many companies to identify racism within organizations, work on community partnerships, and review clinical algorithms for bias. While these sorts of roles used to be most prominent among hospital systems and state offices, several companies—CVS, Humana, and the NFL Players Association, to name a few—recently hired their first health equity executives or officers as the industry grapples with global health disparities. In the wake of the growing number of chief medical officers at Big Tech companies as well as in the retail industry, health equity positions are expected to follow suit.

CONSIDERING ENVIRONMENTAL IMPACTS OF HEALTH CARE

WHAT IT IS

Efforts to reduce ecological footprints of health care labs and facilities are gaining momentum, with areas like water consumption, waste reduction, and pharmaceutical development the most readily available for improvement. Key to this effort are advancements in remote care.

HOW IT WORKS

Most hospitals are focused on adopting circular economies to enhance sustainability by implementing practices that prioritize resource efficiency, waste reduction, and the reuse or recycling of materials. Cardinal Health's Sustainable Technologies, a leading provider of single-use device (SUD) collections, reprocessing, and recycling services in the US, has expanded its facilities, allowing for testing new ways to reprocess medical products. In 2022, the company collected 18.3 million SUDs, diverting more than 5.6 million pounds of waste from landfills. This reprocessing contributes to a circular economy—extending the life of devices to reduce both product cost and waste. A collaboration between the Health Innovation Centre of Southern Denmark, Danish Technological Institute, GMAF Circular Medico, and BD is assessing the viability of recycling used blood collection tubes, currently disposed of via incineration, to reduce greenhouse gas emissions. The pilot program at Odense University Hospital aims to demonstrate the reusability of plastics in health care facilities. As pressure on hospitals systems to reduce their carbon footprint mounts, suppliers will need to provide carbon data. Organizations like Vizient are incorporating carbon emissions information into their contract templates, so providers can make informed purchasing decisions.

WHY IT MATTERS

Hospitals account for 8.5% of the US carbon footprint. Health care laboratories and facilities are inherently energy-intensive and water-consuming, and generate substantial hazardous waste, making them a significant contributor to global water shortages, greenhouse gas emissions, and pollution. In response, health care organizations globally continue to actively adopt sustainable measures, including energy-efficient building designs, renewable energy sources, waste reduction through recycling programs, and effective hazardous waste management. However, with the continued growth of telehealth and remote care options, the industry is poised to greatly decrease its environmental impact. Beyond cost savings and convenience for consumers, the benefits of telehealth include curbing the carbon emissions associated with commuting, minimizing the need for physical infrastructure expansion, and streamlining distribution processes for an optimized supply chain. As the adoption of telehealth expands, sustainable procurement and manufacturing practices are gaining traction, with a focus on sourcing materials with minimal ecological footprints and optimizing drug production processes. Still, the industry is ripe for change, yielding significant opportunities for innovation from outside the industry.

HEALTH CARE ADMINISTRATION

HEALTH DATA INFRASTRUCTURE

WHAT IT IS

More than ever before, we have greater access to an abundance of data points that help us evaluate individual health and well-being. And yet, getting a complete picture of our overall health continues to be a challenge. The widespread adoption of AI is playing a pivotal role in connecting the dots between EHR systems and patient-generated health data to provide a more comprehensive, real-time, and personalized view.

HOW IT WORKS

As of 2021, fewer than 10% of health care organizations had been utilizing AI for more than five years. As AI advancements expand to the health data infrastructure, tools and platforms to improve process workflow are being introduced into the health care industry. Software as a Medical Device can be used to diagnose, monitor, and treat and/or prevent medical conditions. Google Cloud introduced an AI-powered search capability through the Vertex AI Search platform for health care workers to retrieve information from clinical notes, scanned documents, and EHRs, seamlessly and efficiently. Microsoft Fabric aims to simplify the analytics process through an end-to-end, unified analytics platform that integrates various data and analytics tools into a single product.

Patient-generated health data refers to information like vital signs, symptoms, and lifestyle details generated by patients themselves. Health technology platform Folia Health is expanding its patient-reported data collection to include multiple sclerosis, Huntington's disease, and myasthenia gravis. Patients and caregivers can use it to capture their daily observations of treatment response and disease progression. And Oracle is expanding its partnership with Zoom to enhance telehealth services; the collaboration will connect Zoom's telehealth capabilities with Oracle Cerner Millennium, so providers can seamlessly join patient appointments with relevant EHRs.

WHY IT MATTERS

The convergence of electronic health systems and patient-generated health data herald a new era of personalized care, leveraging technology to provide a comprehensive view of an individual's health. The clinical data of EHR systems now seamlessly integrate with patient-generated health data collected from wearables and apps. This mingling gives providers access to a continuous health narrative. As patients produce and record real-time data, integration with their EHRs enables more accurate insights that even consistent medical appointments cannot provide. Introducing a greater volume and diversity of health data facilitates more informed and shared decision-making. Essentially patients become active participants in their care as a collaborative relationship in their health needs forms.

But this integration poses challenges for the health care data infrastructure. Seamless integration requires interoperability between EHR systems and the disparate sources of patient-generated health data, leading to investments in robots, health information exchange (HIE) platforms, APIs, and standardization efforts. Integration efforts must be scalable and able to safeguard the growing volume and variety, and sensitivity of health data. Harnessing the full potential of integrated health data ushers in a new era of preventive and personalized health care.

DEFINING PATIENT ACCESS TO MEDICAL DATA

WHAT IT IS

Amid the increased volume of patient-generated data due to recent innovations, policymakers are grappling with the need for revised regulations and policies that will address the evolving landscape of health data ownership and privacy.

HOW IT WORKS

In April, Washington state's governor signed the My Health My Data Act, a first-of-its-kind consumer health data law that requires explicit consent to collect and share consumer health data. Aimed at addressing gaps not covered by the Health Insurance Portability and Accountability Act (HIPAA), the law prevents traditional advertising practices while even prohibiting some, like geofencing around health care facilities. Following suit, several other states, including California, Colorado, Connecticut, Utah, and Virginia, have taken action to strengthen protections of personal health data. Similar laws aim to safeguard consumers from the unwarranted sale of personal health information. In 2023, safeguarding action was taken against several companies, including Costco, BetterHelp, and Premom, which were accused of selling private patient information. In Europe, legislators still debate how the European Health Data Space (EHDS) regulates the secondary use of health data, such as sharing for research purposes or policymaking. The EHDS aims to provide a single market for electronic health record systems, medical devices, and AI systems while enabling EU citizens to share and have access to their health data across borders.

WHY IT MATTERS

The debate about patient ownership of health records continues to grow, with some arguing that not all health data is generated by the patient and should therefore not belong to the patient. While the EU's General Data Protection Regulation and HIPAA do not explicitly define ownership rights, they acknowledge patients as data subjects, giving them increased ownership, including the right to access their medical data and restrict its use by other parties.

As technology has shifted the way that health data is produced and collected, a greater volume of data exists. Patient-generated health data allows for more accurate real-time data to be collected outside of clinical environments. Access to this information can be game-changing, and lead to further innovations in the industry. Researchers and pharmaceutical and biotech companies also face a paradigm shift: With consumers in control of their personal data, these institutions may need to leverage incentives to access the data necessary for their work. Trust and consumer sentiment will likely play a role in whether access is granted. The changes may usher in new intermediaries to facilitate data access, to service this need on behalf of institutions.

INCREASING INTEROPERABILITY OF DATA INFRASTRUCTURE

WHAT IT IS

The fragmented state of the health care industry's infrastructure is a result of the incompatibility between health care devices, applications, and information systems, which hinders the seamless exchange of patient data and information. Increasing interoperability is a necessary and welcome change.

HOW IT WORKS

The Office of the National Coordinator for Health Information Technology (ONC) reported increased hospital engagement in key interoperability domains, with 6 in 10 hospitals actively participating in information sharing and integrating summary of care records into EHRs. This is promising, as the ONC advances data sharing and interoperability through the 21st Century Cures Act. The office's proposed provisions, known as HTI-1, focus on implementing the EHR reporting program and revise the ONC Health IT Certification Program. Most notably the changes expand exceptions to information-blocking regulations in support of information sharing.

Among companies, Philips achieved enhanced interoperability between its Capsule Medical Device Information Platform and the Patient Information Center iX, giving hospitals the ability to synthesize data from a variety of non-Philips devices—like third-party vital sign monitors, ventilators, and infusion pumps—and view the information on a single, standardized interface. CareSource IT addresses health care data interoperability challenges through API utilization. Michigan Health Information Network Shared Services and Amazon Web Services are launching Interop.WORLD, a virtual innovation center focused on health care interoperability. The center plans to host challenges using an open-source health data sandbox to encourage developers and organizations to design cloud-based health care IT solutions that support interoperability.

WHY IT MATTERS

Limited data exchange has been a growing issue since medical providers first implemented EHRs, and many benefits can be realized by facilitating the rapid exchange of health information. This approach can optimize human capital, patient-centric care, and public health emergency preparedness. Providers will experience reduced turnaround times, enabling them to render higher-quality care services to their patients. Patients will be more engaged in self-managing their well-being. The public will also benefit from early detection and prevention of disease outbreaks.

Despite this, achieving interoperability is a complex challenge. Overcoming these challenges will require a willingness of stakeholders to collaborate on information exchange. Blockchain-based HIEs, like MedRec, OmniPHR, and MeDShare have gained traction, as have Fast Healthcare Interoperability Resources, like Google Cloud, Epic, Cerner, and Allscripts. These are promising tools to facilitate seamless data exchange and collaboration among health care providers. However, ensuring the security and privacy of patient data remains a paramount concern. Governments are likely to regulate interoperability standards and practices, with US compliance requirements like HIPAA and the Cures Act shaping the landscape. Financial constraints and varying levels of readiness, especially for smaller providers, pose challenges in adopting the necessary infrastructure and technologies, potentially leading to industry consolidation.

5TH YEAR ON THE LIST

AUTOMATION OF PROCESSES

WHAT IT IS

Automation is transforming health care, making the industry more efficient and reliable. Big Tech is championing workforce automation while introducing process efficiency solutions for appointment scheduling, billing, supply chain management, health management, admissions and discharges, follow-up care, prescription management, quality assurance, and compliance.

HOW IT WORKS

Last year saw a rise in AI-generated note-taking tools as several companies, including Microsoft and Amazon, launched their versions. Microsoft-owned Nuance Communications released its Dragon Ambient eXperience Copilot, which is integrated with large language model GPT-4 and automatically drafts clinical summaries of conversations with patients conducted in an exam room or via telehealth. Amazon Web Services introduced HealthScribe, a new HIPAA-eligible service that leverages speech recognition and generative AI to automatically create preliminary clinical documentation from patient-clinician conversations. Microsoft's cloud division Azure is releasing a new functionality for clinical report simplification. With the use of generative AI, the tool simplifies clinical jargon so patients can better understand medical information. OpenLoop's API-driven platform can be aligned to meet workflow needs and securely houses patient personally identifiable information with its built-in HIPAA compliance software.

XTend Robotics has developed patented robot technology to deploy modular service robots that can adapt to any industry. Multitasking intelligent robots can be used in hospitals and ambulatory care facilities to interact with patients, automating the check-in and vitals collection process. Increasing efficiency over 70%, the robots take dictation and automatically update patients' files on the facility's EHR system.

WHY IT MATTERS

Automation, driven by technologies such as AI and robotic process automation (RPA), leads to greater efficiency, accuracy, and improved patient outcomes. Administrative tasks, appointment scheduling, billing, and data entry, which traditionally demanded significant human resources, can now be streamlined. Though there is an upfront cost for adoption, the automation of processes will save time and preserve limited staff. Automation enables health care providers to focus more on direct patient care. Moreover, in clinical settings, AI-driven tools aid in diagnostics, treatment planning, and personalized care, leveraging vast data sets to identify patterns and make data-driven predictions. Automation promises a minimal standard of care, reinforcing adherence to regulation and quality assurance.

1ST YEAR ON THE LIST

INCREASED CYBERSECURITY THREATS

WHAT IT IS

Cybersecurity concerns are on the rise, and the threat to health care organizations, information systems, and patient safety are substantial. According to IBM's Cost of Data Breach 2023 Report, the global average cost of a data breach in 2023 was $4.45 million, a 15% increase over three years.

HOW IT WORKS

In a Ponemon Institute survey of 653 health care IT and security practitioners, 88% of respondents reported experiencing an average of 40 cyberattacks within the past 12 months. A significant number of large companies have experienced some sort of a breach. PharMerica, operated by parent company Bright Spring Health, disclosed a breach to the Office of Civil Rights in May that impacted more than 5.8 million people. Managed Care of North America suffered a major data breach that lasted nearly two weeks, impacting 8.8 million people. Henry Schein, distributor of medical and dental supplies, announced a cybersecurity attack that caused the company to take systems offline. 23andMe issued a notice of data concerns due to suspicious activity at its operations in October. Perry Johnson & Associates, a US medical transcription service, fell victim to a cyberattack that exposed highly sensitive information of 9 million patients, the second-largest after HCA Healthcare's 11 million-record earlier in the year. And a new ransomware threat, NoEscape, has targeted the health care industry. Despite being new to the landscape, the ransomware group has very rapidly made a name for itself. In response to the increase in threats, UC San Diego School of Medicine was awarded $9.5 million to research cybersecurity in health care and launched its Center for Healthcare Cybersecurity, which will focus on identifying early indicators of cyberthreats using simulated ransomware.

WHY IT MATTERS

PwC's Global Digital Trust Insights survey reveals a concerning trend: Businesses experiencing data breaches resulting in damages exceeding $1 million jumped from 27% to 36% in the past three years. While traditional threats like ransomware, DDoS, and social engineering persist, emerging cyberattack categories include biomalware, medical deepfakes, and machine learning simulations mimicking users' digital activities. Of particular concern is biomalware targeting and manipulating biological systems, such as DNA. This biomalware can take various forms, such as viruses or Trojan horses operating at the genetic or cellular level, and can be used to disrupt research, harm individuals, or access genetic information.

AI-powered security solutions have introduced groundbreaking features, such as continuous threat monitoring, anomaly detection, predictive analysis, and vulnerability assessment. AI's ability to process vast amounts of security data can predict vulnerabilities and automate patch management. AI is especially adept at identifying zero-day exploits, when an attacker identifies a software vulnerability even before the vendor has become aware of it. A first-of-its-kind unified security platform, Microsoft Security Copilot integrates tools for automatic detection and response. Recently IBM introduced Threat Detection and Response Services, an AI-enabled service delivering 24/7 monitoring, investigation, and automated remediation of security alerts across hybrid cloud environments.

SCENARIO YEAR 2040

SCENARIOS

SCENARIO YEAR 2040

Biological Data Vaults

To increase data security and enable environmentally sustainable storage of our data, a new solution emerged in the early 2030s: encoding sensitive information directly into human DNA. This technique, which leverages the vast data storage capacity and unique personal signature of DNA, converts critical data such as medical and financial records into nucleotide sequences. The approach transforms individuals into secure carriers of their own encrypted information.

But recently, this innovative system became the focal point of a sophisticated cyberattack, orchestrated by a rogue state-sponsored hacking group to undermine trust in this new technology and to extract high-value information for espionage and financial gain. The attack employed a digital virus specifically tailored to breach the interface between biological and digital security systems. It was introduced into the population through common medical channels, such as standard blood tests or vaccines, using genetically modified vectors to deliver the payload.

Once inside the host, the virus lay dormant until remotely triggered. Upon activation, it employed complex algorithms to decode the encrypted data stored within the DNA and converted it back into a digital format. The virus harnessed the body's bioelectrical system, which is primarily generated through the activity of neurons and the body's way to communicate internally, to transmit this data to the attackers, leaving no physical evidence of the breach. The modified electrical signals the neurons produce because of the virus are received by sensors specifically designed to detect and interpret these bioelectrical patterns.

Once the data was extracted, the hackers engaged in a dual-pronged approach: They sold sensitive personal and financial information on the dark web, targeting high-net-worth individuals and key corporate figures for identity theft and financial fraud. They also exploited corporate and governmental data, which was stored in the DNA of leadership individuals, for espionage, seeking competitive intelligence and state secrets to threaten overall geopolitical security.

REMOTE CARE

IN-HOME CONSUMER HEALTH TECHNOLOGY

WHAT IT IS

Digital biomarkers are behavioral and physiological data, such as heart rate, blood pressure, body temperature, sleep patterns, and physical activity, collected through digital devices. Smart home technology is evolving to facilitate the monitoring of digital biomarkers, creating an integrated ecosystem for health information that complements wearables.

HOW IT WORKS

It's easier than ever for consumers to measure and monitor their digital biomarkers. Freestyle Libre's continuous glucose monitoring wearable sensors received FDA clearance for connectivity with automated insulin delivery systems. Abbott is introducing Lingo, a wearable that will measure glucose levels for people without diabetes and deliver personalized plans for healthier habits. Somavedic Technologies launched the Attune Health app, which takes AI-enabled biomarker analysis of blood pressure, heart rate, oxygen saturation, stress levels, and hemoglobin based on a facial scan on a smartphone camera. It measures changes in red, green, and blue light reflected from the skin. The Gao Lab at the California Institute of Technology introduced a finger patch for microfluidic sweat sampling of estradiol. Only requiring a miniscule amount of sweat, the device consistently learns and recalibrates based on salt levels, skin temperatures, and sweat pH. The team is working to miniaturize the sensor for placement in a ring, as the device can already wirelessly communicate with an app.

Today's digital biomarkers are not limited to wearables; they're also making their way into the infrastructure of the home. With the U-Scan from Withings, a sensor is placed under the rim of a toilet bowl to measure biomarkers and metabolites in a person's urine. A recently approved patent application shows that Apple, which purchased Finnish technology company Beddit, is developing an in-bed sensor system to collect physiological data during sleep.

WHY IT MATTERS

Biosensors, compact devices designed to detect biological elements and convert them into measurable signals, are increasingly finding their way into homes. Imagine furniture textiles that measure vital signs to predict minor sickness and maintain body temperature, toothbrushes that detect dehydration and make dietary recommendations, optical sensors in televisions that can detect stress and cognitive decline, windows that can measure vitamin D deficiency and control smart light bulbs in response, smart plumbing that can filter bacteria from the water supply, and air purifiers that measure clean oxygen supply and recommend houseplants to improve air quality. Whether these sensors are integrated with wearable devices or standalone units, the technology offers a comprehensive view of our well-being by tracking vital signs and other health parameters in real-time. Revolutionizing personal health care management, biosensors empower users to make informed decisions for fostering preventive health care.

While the integration of biosensors into everyday life offers unprecedented benefits, it raises concerns about data security and privacy. Given the ability to generate vast amounts of data, there are necessary ethical considerations surrounding data usage. Our homes will play a crucial role in health management, and if the health data infrastructure can overcome challenges stemming from data standardization and interoperability, expect to see further development supporting holistic sensor ecosystems. In 2022, the global market for biosensors was valued at $26.8 billion, and it is projected to grow significantly in the coming years.

4TH YEAR ON THE LIST

SCALING OF TELEMEDICINE

WHAT IT IS

Telemedicine leverages technology for remote health care delivery. While the Covid pandemic initially prompted the emergence of remote care options,the trend is clearly here to stay and will even expand beyond primary health. The market is forecasted to be valued at $460 billion by 2030.

HOW IT WORKS

The global telehealth market is on track to achieve remarkable growth due to increasing technology adoption. AI and machine learning play a crucial role, by providing personalized, predictive, and preventative guidance, which has helped telehealth evolve beyond primary health virtual consultations to encompass virtual pharmaceutical, translation, and surgical services. The Midday app facilitates direct communication to promote healthy aging. Aimed at supporting menopausal women, the end-to-end platform evaluates menopause progression to deliver personalized insights, and evidence-based strategies and education. Amazon's RxPass, a $5-per-month subscription, offers affordable and convenient pharmacy services without insurance. Subscribers can have generic medications for more than 80 common health conditions sent to their home. Voyce introduces professional language interpreters, enabling real-time medical interpretation in more than 240 languages, including American Sign Language. The technology seamlessly integrates with EHRs, automatically documenting sessions for future reference. In Singapore, a groundbreaking robotic telesurgery trial utilized Japan's first surgical robot. It remotely performed a gastrectomy from a Singapore-based surgeon cockpit, with movements transmitted and replicated by a robotic unit in Japan. This collaboration represents a pivotal stride in making remote surgeries accessible to patients, demonstrating the transformative potential of telehealth.

WHY IT MATTERS

Consumers are increasingly comfortable with telemedicine options. In a recent study, 55% of patients expressed more satisfaction with virtual visits than in-person visits. Rural communities and underserved populations stand to gain the most as health care providers expand their reach and fill gaps in care delivery caused by provider shortages and limited facilities. And there's potential for cost reduction on both ends of the spectrum: Subscription services, available with or without insurance, are more affordable, while providers benefit from the savings associated with not maintaining physical offices. Investments in telehealth have also expanded to specialty care, and the future of telemedicine could include extended reality (XR) technology offering more lifelike virtual interactions, especially for remote surgery.

But access remains a big hurdle due to challenges related to digital technology access and connectivity. Zero-latency connectivity is essential for virtual visits, as it ensures real-time guidance and critical decision-making without delay. Starlink provides almost global satellite coverage, and Amazon launched Project Kuiper, a satellite system aimed at providing high-speed internet access globally. With the promise of reliable access to broadband, the system's success will be a game changer for achieving interoperability. The attainment of global connectivity is poised to reduce the prevalence of medical tourism, by making telemedicine a more reliable and accessible alternative.

REMOTE PATIENT MONITORING

WHAT IT IS

As the population ages, remote patient monitoring (RPM) is increasingly relevant for achieving a higher quality of life. RPM ensures continuous communication between patients and their health care provider team by utilizing digital technologies and devices to collect and transmit patient health data outside of traditional health care settings.

HOW IT WORKS

Increasingly, health data can be transmitted to providers from anywhere, and companies are offering new services to take advantage of the trend. A new hospital-at-home program from Best Buy collaborating with Atrium Health sends members of the retail giant's Geek Squad to patients' homes; they set up technology that remotely monitors heart rate, blood oxygen level, or other vitals, and train patients and caretakers to use the devices. The tech then securely shares the data with doctors and nurses through the telemedicine hub from Current Health, a UK-based tech company. There's also Cardinal Health's Velocare, a supply chain network for the fulfillment of care devices and products. In coordination with care teams, Cardinal Health facilitates seamless delivery of medical essentials to home care patients, eliminating challenges in transitioning hospital care to a patient's home.

On the equipment side, Noccarc's smart ventilator enables real-time remote monitoring of patient conditions. Physicians can seamlessly access vital patient information through a proprietary app-based platform, even when patients are not physically present in the ICU. BioPix-T launched Pebble, a portable diagnostic device to facilitate connections between health care providers and patients: It enhances access to the tools needed to detect and monitor infectious diseases and health issues despite geographic location. Sleepiz, a Zurich-based medtech company, received FDA clearance for its Sleepiz One+, a contactless bedside device that measures respiratory and heart rates.

Researchers at NYU Langone Hospital have also launched the Diabetes in Pregnancy Remote Patient Monitoring Program. The pilot program has supported 1,000 patients at risk for gestational diabetes with digital glucose monitors that automatically transmit daily glucose levels to EHRs for review by the maternal-fetal medicine team.

WHY IT MATTERS

RPM harnesses digital technologies in the continuous collection and transmission of patient health data, allowing patients to receive necessary care anywhere. The ability to facilitate prompt interventions makes it particularly valuable for managing chronic conditions, monitoring postoperative recovery, and delivering ongoing home-based care. Particularly pertinent as the population ages, RPM ensures a higher quality of life for geriatric adults by enabling hospital-level care in the comfort of their homes, with medical-grade equipment and remote monitoring tools. Hospital-at-home services offer significant cost savings for health care systems by curbing hospital admissions and emergency room visits through early intervention and improved disease management. Patients also benefit from increased engagement in their health monitoring through better outcomes. As such there has been a growing adoption of hospital-at-home devices and telemedicine technology in senior care and assisted living facilities, where the integration of these innovations enhances on-site care for residents. Though broader adoption in patients' homes has been slow, this hesitance is likely due to space constraints or limited support (i.e., family members, nurse aides) preventing consumers from feeling comfortable or safe receiving care outside clinical facilities.

SCENARIOS

SCENARIO YEAR 2035

The Optimization Score

The health care industry's lethargy in responding to change led the Big Tech companies to fill the void with cheaper, higher quality, and more price-transparent products and services. Already trusted partners in a personal and professional context through their hardware and software products, integrating health care offerings was actually welcomed as it facilitated a holistic and seamless approach to optimizing quality of life.

The digital ecosystems continually capture and synthesize health data from a myriad of sources: wearable devices, smart home systems, and even public infrastructure. AI health platforms meticulously analyze this data, and synthetic "health coaches" offer tailored suggestions to optimize physical and mental well-being. This constant monitoring and guidance ensure that individuals are not just living but thriving, under the vigilant eye of technology.

To incentivize healthier living and alleviate the strain on health systems, a health scoring system was introduced, reminiscent of the credit scores of the early 21st century. The Health Score, a dynamic and comprehensive metric, reflects an individual's health habits, lifestyle choices, and overall well-being. Initially devised as a tool for personal motivation and friendly competition, it quickly evolved into a societal benchmark, a digital ledger of one's health consciousness. The Health Score is not just a number; it's a reflection of one's commitment to a healthy lifestyle, tracked and fostered by ever-present AI.

This scoring system has profound implications on everyday life. High scorers enjoy perks ranging from priority in job applications and access to exclusive amenities, to favorable terms on loans and insurance policies. Displayed on digital profiles and wearable device screens, the score has become a status symbol, a digital badge of honor showcasing a person's dedication to health. In contrast, those with average or low scores, or those who opt out of this system, find themselves at a significant disadvantage. They face hurdles in securing employment, higher premiums, and restricted access to certain societal privileges. The Health Score, while not mandatory, has become a de facto requirement for a comfortable and prosperous life.

EMERGING DIAGNOSTICS

2ND YEAR ON THE LIST

SMART MATERIALS

WHAT IT IS

Incorporating sensors into textiles offers noninvasive data collection for advanced health monitoring and analysis. The smart textiles market is expected to grow to $6.6 billion by 2026. But scalability presents formidable challenges, as these textiles must be able to endure prolonged use while continuing to deliver accurate measurements.

HOW IT WORKS

Right now, the field is focused on overcoming manufacturing challenges that hinder scaling of smart textiles. In collaboration with researchers at the University of Cambridge, scientists from Aalto University have incorporated liquid crystalline elastomer yarns into woven textiles to create a reactive fabric that responds to heat. At Purdue University, researchers are looking at smart fabric breathability, as it is associated with comfort: They've developed a patent-pending method of coating everyday fabrics with polymer electronic sensors, PEDOT, using a technique called oxidative chemical vapor deposition. MIT researchers have used a unique plastic yarn to create a knit textile, 3DKnITs, that when interspersed with sensors using a novel digital knitting technique, can continuously detect multipoint pressure across its surface in real-time. A new cotton-based conductive thread, PECOTEX, developed by scientists at the Imperial College of London, embeds a low-cost sensor (just 15 cents per meter of thread) to monitor breathing, heart activity, and even gases like ammonia. Israel-based company HealthWatch has emerged as a pioneer in the development of smart-digital garments, particularly with its development of the Master Caution. The only 12-lead ECG smart clothing that has been cleared by the FDA, Master Caution is a sensor-rich textile garment that provides continuous cardiac monitoring.

WHY IT MATTERS

Embedding sensors into textiles is a minimally invasive avenue to collect data about daily activity and environmental exposure. Compared to wearables, smart materials are more versatile, adaptable, and less disruptive to consumers' lives. Their integration lets consumers receive real-time feedback, promoting healthier habits. And their ability to generate substantial data offers valuable insights for continuous health monitoring, early detection of medical conditions, and remote patient care. Scientists are considering ways to monitor and respond to biological hazards and environmental conditions, including air quality, pollution levels, and radiation exposure. Advancements in materials and production methods suggest that smart textiles could greatly reshape the industry.

Researchers are exploring innovative materials, such as spider silk and elastomers, and cost-effective production methods, including traditional industrial knitting machines. But challenges with scaling production have prevented smart textiles from flooding the market just yet. Concerns have also arisen regarding the potential effects of increased electromagnetic field exposure. At this juncture, the military is expected to account for a sizable amount of the market for smart textiles, as applications include enhanced insulation, motion tracking and GPS, and advanced health monitoring. For the broader population, smart textiles hold immense promise in the shift toward personalized care and holistic health.

1ST YEAR ON THE LIST

BIOSENSOR AND CHIP-BASED DIAGNOSTICS

WHAT IT IS

Biosensors recognize biological material as it binds to a specified target and convert the biological response into a detectable signal. Advanced data analysis and machine learning techniques are being integrated with biosensors to enhance diagnostics by recognizing patterns and trends in large data sets.

HOW IT WORKS

Researchers are developing new tools using biosensors to uncover new biological insights. Wireless earbuds, developed by MindMics and Scripps Research Institute, use embedded sensors to record heartbeat vibrations once a second to indicate heart disorder and abnormalities. Researchers at Ohio State University designed a wearable sensor, resembling a blood pressure cuff, to detect muscular atrophy. The device embeds transmitting and receiving coils in a flexible fabric to measure deterioration as it stretches to a person's movement.

An international team led by the Gwangju Institute of Science and Technology has proposed a synergistic biosensing tool called DeepGT. It leverages AI in Gires-Tournois biosensing platforms to quantify nanoscale bioparticles, including viruses, without needing complex sample preparation methods. The system can also indicate the severity of the infection including if it's asymptomatic.

A Malmö University researcher developed a wireless battery-free biosensor powered by induction from a cellphone. A nanoscale sensor system, put together by a team at the University of Toronto and Northwestern University, identifies biomarkers by exploiting DNA aptamers to detect clinical levels of a marker protein for cardiovascular disease without using external reagents. And Hememics Biotechnologies and General Graphene have partnered to produce 32-plex graphene biosensor chips, tested to be 100 times more sensitive than lateral flow devices; the chips can detect pathogens from one sample of blood or saliva.

WHY IT MATTERS

Biosensors offer a paradigm shift in patient diagnosis through the early detection of medical conditions. Recent advancements are focused on highly sensitive and versatile sensors capable of performing multiple tests simultaneously despite the presence of different biological particles at varying concentrations. Biosensors have application in industries where precise and rapid detection of harmful substances is crucial. Beyond a clinical setting, biosensors can be used to detect contaminants and pathogens—for example, spoilage indicators in food products, or pollutants and toxins that affect air and water quality.

With the acceleration of point-of-care diagnostics, researchers are working on the development of microfluidic chips with embedded biosensors for greater precision. The integration of these concepts in a highly sensitive portable device paves the way for remote diagnostics. As biosensors are increasingly incorporated into wearable and in-home devices for continuous monitoring, the need for frequent in-office or hospital visits decreases.

MOLECULAR DIAGNOSTICS

WHAT IT IS

Molecular diagnostics leverage the sensitivity and accuracy of CRISPR technology to analyze genetic material for early detection of disease, aiding timely intervention. The application of CRISPR in developing advanced molecular diagnostic tools enables interventions based on individual genetic profiles and opens up more effective and precise health care strategies.

HOW IT WORKS

At the University of Oxford, researchers have innovated a method for protein analysis to efficiently build protein inventories of single cells and tissues. This new categorization method makes it easier for doctors to identify the protein variants associated with disease on an individual basis. Genomic sequencing company Illuma developed PrimateAI-3D, which is trained to make predictions based on genome analysis and scans 70 million genetic variants in a person's genome to detect harmful variants. Illumina plans to release the tool broadly, after completing testing on the UK BioBank. While identification and analysis are key to preventative diagnostics, just as important is recognizing abnormal activity. Researchers at Weill Cornell Medicine have developed a novel method for organ mapping that could inform the design of future treatment and interventions. Spatial PrOtein and Transcriptome Sequencing can record gene activity patterns, identify key proteins, and map precise locations of cells in tissue samples.

An increasing number of health care institutions, like UCSF Benioff Children's Hospital, are implementing in-house rapid whole genome testing to assess and diagnose risk for infants with suspected genetic diseases. Ultra-high-throughput gene sequencers aim to make whole genome sequencing more affordable, as two companies, Ultima and Complete Genomics, introduce platforms that lower costs to less than $100 per genome.

WHY IT MATTERS

In infectious disease control, molecular diagnostics are pivotal for rapidly and accurately detecting viruses and bacteria. This capability is critical for implementing timely public health measures, and techniques like polymerase chain reaction, DNA sequencing, and microarrays enable the early detection often before symptoms manifest. This allows for a shift in focus toward developing informed treatment plans rather than simply identifying the problem. Harnessing CRISPR, researchers have developed highly specific tests for detecting genetic mutations, pathogens, and various molecular markers. The integration of CRISPR into biosensors has further advanced on-site testing capabilities, fostering the creation of rapid and accurate point-of-care diagnostic tools. Notably, scientists used CRISPR in the development of rapid tests for detecting Covid.

Anticipating a fundamental shift in health care practices, molecular diagnostics, augmented by AI and nanotechnology, is set to become routine in patient care. Efforts are underway to enhance user-friendliness and cost-effectiveness for accessibility across different health care settings, and even at-home use. Integration with wearables and telemedicine platforms is on the horizon. The prospect of full-genome screening tests for newborns and infants is gaining momentum, with studies showing whole-genome sequencing to be much more effective than targeted gene sequencing in identifying abnormalities responsible for genetic disorders.

INCREASED CAPABILITIES OF POINT-OF-CARE DIAGNOSTICS

WHAT IT IS

Conveniently performed near a patient, point-of-care (POC) diagnostics offer speed, convenience, and accessibility. Now, smartphone-enabled POC devices enable real-time data transmission and expand the reach of telemedicine. Modern POC devices can perform multiple tests simultaneously, allowing for the detection of various diseases or conditions from a single sample.

HOW IT WORKS

Polish telemedicine startup Healthnomic offers an at-home polygraph examination to remotely diagnose and treat obstructive sleep apnea, by gathering data in a patient's natural sleeping environment. GrapheneDx is harnessing graphene in developing urine-sample tests to detect sexually transmitted diseases within minutes. A new facial recognition software for germs, developed by Oxford scientists and licensed by Pictura Bio, is a universal diagnostic imaging platform that identifies the presence of pathogens in a nasal or throat swab sample in seconds. Quest Diagnostics has introduced the AD-Detect test for Alzheimer's disease, a blood-based biomarker test available for purchase by consumers. AD-Detect overcomes current diagnostic methods—limited by the need for specialized clinics and trained staff—through an in-home blood test that determines risk for developing Alzheimer's disease by measuring abnormalities of beta-amyloid protein. At-home diagnostics startup Viome Life Sciences has launched Oral Health Pro with CancerDetect, to detect biomarkers associated with oral and throat cancers. With a specificity of 95% and sensitivity of 90%, the test uses RNA sequencing technology and AI to measure gene expression of the oral microbiome and cells of each patient's saliva. Though these and similar tests are still ordered and evaluated by physicians, they're a first step—albeit an imperfect one—in equipping consumers with convenient methods of early detection.

WHY IT MATTERS

POC diagnostics offer immediate on-site medical testing with results made available in real time. Common examples are rapid tests to identify infectious diseases (used to combat the Covid pandemic), pregnancy tests, and glucose monitoring. Unlike traditional laboratory testing that involves sending samples to centralized facilities, POC diagnostics bring testing to the patient, minimizing delays in triage and treatment. They reduce the workload on central laboratories, by addressing backlogs and delays in test results. In resource-limited settings, where access to sophisticated laboratory infrastructures is limited, POC diagnostics present a new level of care. In developing worlds, POC diagnostics could make a difference in the rapid spread of disease.

Integral to telemedicine and remote monitoring, POC allows health care providers to assess patients' conditions and make decisions without the need for in-person visits. Recent developments in POC testing include: wireless integration for real-time results and insights to be delivered via an app, portable diagnostic devices that can perform multiple tests simultaneously from a single sample, and customization of biomarker panels for testing of specific diseases or conditions. In addition, POC devices for gene sequencing and molecular diagnostics are on the horizon. For the adoption of a patient-centric model, POC diagnostics ensures that medical decisions are as timely as they are accurate.

1ST YEAR ON THE LIST

XR IN DIAGNOSTICS

WHAT IT IS

XR is transforming medical diagnostics by introducing ways to interact with medical data, patient information, and anatomical structures. The technology enables the visualization of disease progression, immersive training simulations, and remote collaboration. While XR holds great promise, issues of data privacy, accuracy, and regulatory compliance should be considered.

HOW IT WORKS

AI and machine learning algorithms are automating the analysis of medical images and aiding in the early detection and diagnosis of disease. Imidex received FDA clearance for VisiRad XR, a machine learning platform that detects subtle, often overlooked, lung nodules on chest X-rays. Nutex Health has integrated DRAid Chest XR into the radiology workflow of its hospitals. A research team led by Michigan Medicine developed DeepGlioma, a AI-based diagnostic system that uses rapid imaging to screen for genetic mutations in brain tumors in under 90 seconds during surgery. Stable Diffusion is an AI-algorithm able to read fMRI brain scans to re-create realistic images based on what a person has seen. The algorithm was recently retrained, enhancing its accuracy. The technology, currently tested on a limited data set, holds promise for further cognitive neuroscience research.

Avatar Medical's VR surgical planning solution, which generates patient avatars from CT scan and MRI images, has received FDA clearance. GigXR released Dicom XR Library, a platform that generates realistic 3D medical imagery from MRI and CT scans for training and learning purposes. MedView XR received FDA clearance for its XR90 AR platform, which renders 3D images with the use of CT scans during minimally invasive procedures. MedView aims to improve surgical visualization and promote collaboration; it's secured $15 million in funding from notable industry players, including the Mayo Clinic and GE Healthcare.

WHY IT MATTERS

XR technologies offer new ways for health care professionals to visualize and interact with medical data, patient information, and anatomical structures. Using head-mounted wearable technology, XR technologies can integrate real-time patient data and diagnostic history into a clinician's field of view during medical examinations for more accurate diagnostics. Beyond the exam room, XR facilitates remote collaboration and fosters communication between patients and medical professionals. Experts from different locations can virtually collaborate on diagnosing complex cases, share insights, and arrive at accurate diagnoses more quickly. Through immersive explanations and visualizations of medical conditions, XR enhances patients' understanding of symptoms and overcomes language barriers. Interactive 3D models can potentially support medical professionals in explaining their diagnosis and treatment plans to patients. Overall, patients will better understand their conditions and treatment options and make more informed decisions.

In imaging interpretation, virtual reality and augmented reality enhancements enable radiologists and imaging specialists to immerse themselves in detailed 3D reconstructions of patient scans. Medical students and practitioners can also train on XR platforms to refine their diagnostic skills in a risk-free environment and practice patient interactions through simulated office visits. Medical students can also study disease pathology through the visualization of disease progression. While the promise of XR in medical diagnostics is evident, it's imperative to address concerns of data privacy, accuracy, and regulatory compliance. As XR technologies advance, they will likely play an increasingly prominent role in the medical diagnostics process.

MEDICAL DEEPFAKES

WHAT IT IS

Medical deepfakes involve the use of AI to manipulate medical data or images and present a double-edged sword: They're promising for the advancement of medical education and research, but involve substantial risk when used maliciously. Amid AI's rapid sophistication, health care organizations have been slow to regulate.

HOW IT WORKS

Given the difficulty in deciphering real and synthetic data, deepfakes compromise data integrity. A study in Finland demonstrated that on average, more deepfakes were mistaken for real X-ray images than the opposite. A surge in deepfakes has prompted insurance companies, including Aetna and Cigna, to deploy machine learning algorithms to evaluate insurance claims, and nearly 60% of insurers are using this fraud detection strategy to ensure fair and accurate coverage. Though the action is justifiable, it has led to unintended consequences, like the mislabeling and subsequent denial of legitimate claims.

Clinical-stage drug discovery company Insilico Medicine is utilizing deepfakes to design molecules with disease-treating ability. Its AI platform, Pharma.AI, can discover novel therapeutic targets, formulate new pharmaceutical drugs, and predict the results of clinical trials. Alongside researchers and Nobel laureates, the company applied AlphaFold, Google DeepMind's protein structure database, to Pharma.AI, identifying a novel treatment pathway for hepatocellular carcinoma in only 20 days. Korea University researchers proposed the use of StyleGAN2 to create synthetic mammographic images and an anomaly detection method to detect breast cancer on mammograms. Their generative AI model showed comparable fidelity to real images, while results indicated that the anomaly detection was highly sensitive. The study presents a promising approach for improved breast cancer detection.

WHY IT MATTERS

In a world where deepfakes proliferate, the very essence of the patient-doctor relationship is at risk. Their presence erodes the trust and reliability in the health care system. Researchers conducting studies or clinical trials may use deepfakes to manipulate research findings to skew results in support of a particular agenda or to secure funding. Fraudsters may use medical deepfakes to forge insurance claims or to exaggerate injuries and illness in a personal injury lawsuit. Cybercriminals may use medical deepfakes to gain unauthorized access to patient records and sensitive medical information. Sinister groups may defraud the public during a health crisis or outbreak to generate fear and panic.

While there is a dark side to medical deepfakes, their accuracy can also aid in the development of diagnostic tools and drug treatments, accelerating the pace of scientific discoveries and innovations. When used to generate synthetic data, they ensure patient privacy and compliance with regulations. In training and education, medical students and practitioners can interpret and diagnose a wide range of medical conditions via simulated cases.

The health care industry has only begun to invest in technologies and protocols to detect and prevent deepfake manipulation. A watermark created by DeepMind in partnership with Google Cloud SynthID, the first of its kind, embeds an immutable mark directly into images created by Imagen.

EMERGING TREATMENTS

NANOBOTS

WHAT IT IS

Nanobots offer precise, minimally invasive treatment for targeting disease and improving drug delivery. Concerns include material toxicity and genetic modification, and yet the technology could enable precise and efficient procedures with reduced side effects and adverse reactions.

HOW IT WORKS

Researchers at the Indian Institute of Science and Theranautilus have developed helical nanobots able to penetrate dentinal tubules where antibiotic-resistant bacteria accumulate. Controlled by a magnetic field, the nanobots' heat generating capability was effective in killing bacteria. Similarly, researchers from the University of Pennsylvania have developed magnetically controlled nanorobots with catalytic properties to generate antimicrobial oxygen-containing molecules that eliminate fungi within 10 minutes.

At the Shenzhen Institute of Advanced Technology, self-propelling nanobots offer precise gastrointestinal inflammatory therapy; these TBY-robots penetrate the mucus barrier and autonomously navigate to the inflamed site. MIT scientists developed magnetically controlled soft-bodied polymer robots measuring millimeters long that can navigate confined spaces like blood vessels, enabling the delivery of drugs. A dual-action approach involving the delivery of lactate oxidase enzymes via tiny nanocapsules to promote immune cell activity was developed by researchers at UCLA. Engineers at University of Colorado Boulder developed a self-propelled robot that measures only 20 micrometers wide and can travel at a speed of 3 millimeters per second, demonstrating potential for drug delivery. The researchers hope to make these robots fully biodegradable so that they would dissolve in the human body.

WHY IT MATTERS

The industry is witnessing an unprecedented surge in the integration of robots. At the forefront are nanobots, miniscule robots that operate at nanoscale to perform highly targeted activities in the body. They can deliver medication to a tumor without affecting healthy tissues or perform intricate surgeries in delicate, hard-to-reach areas. Nanobots minimize side effects, reduce immune response, and accelerate recovery time, thereby reducing risks. Extending beyond surgery, they are applicable in telerobotics given the ability to be remotely controlled across distances, enabling prolonged observation of chronic conditions and real-time delivery of drugs.

Equipped with sensors and diagnostic tools, nanobots detect biomarkers and abnormalities. Molecular nanobots can be designed to respond to biological signals, adapting shape and function to conditions within the body. And researchers are exploring self-propelling features for autonomous operation. This would increase the efficacy of cancer treatment through drug delivery and targeted tumor therapy, while the nanobots' ability to navigate the blood-brain barrier also opens avenues for treating neurological disorders. But concerns exist around the possibility of unintended consequences resulting from genetic modification. While synthetic nanobots offer precise engineering, they could be toxic with long-term exposure. Ultimately, the choice whether to use the technology hinges on the medical task, safety considerations, and personalization.

AR/VR THERAPEUTICS

WHAT IT IS

A versatile technology, extended reality is being increasingly used in therapeutics for a wide range of physical and mental health issues including rehabilitation, pain management, exposure therapy, and reducing stress and anxiety. Augmented reality/virtual reality introduces gamification to therapeutic techniques, increasing patient engagement and motivation through immersive experiences.

HOW IT WORKS

A pilot study by Stanford Medicine researchers suggests that VR therapy could help people with a hoarding disorder declutter in real life. The therapy allows patients to rehearse relinquishing possessions in a simulation of their own home, helping them practice skills learned in cognitive behavioral therapy. Immersive VR appears to alleviate pain and distress in cancer patients, according to a pooled data analysis published in BMJ Supportive & Palliative Care. The study suggests that VR may help patients better cope with required medical treatments and the emotional impact of their conditions. Samsung's advanced AI app operating within diminished reality, Unfear, is interoperable with Samsung Galaxy earbuds to filter known trigger sounds to calm and assist patients with autism spectrum disorder, auditory PTSD, and hearing disorders. An Australian startup, RecoveryVR, gamifies VR technology for neuro-rehabilitation. AI Rehab is a UK-based startup that designs telehealth solutions for patients recovering from hip and knee surgeries. Its products combine AR and wearable remote sensors to make it easier for patients to perform pre- and post-operative exercises. Built-in alerts for remote notification and patient-reported outcome measures ensures standardized feedback and measurable data.

WHY IT MATTERS

Governments and industry professionals are under increasing pressure to explore innovative and accessible solutions to address the growing mental health crisis, and XR technology is an incredibly viable way to do this. Through the use of virtual rooms for therapeutic care, XRHealth revealed that VR therapy reduces stress and anxiety in patients by 34%. The study underscores the efficacy and accessibility of VR therapy to provide engaging and effective mental health treatment options. XR technology also allows for remote treatment and monitoring, mitigating risks of unwanted side effects common to pharmaceuticals.

With AR, rehabilitation techniques can be gamified, resulting in increased patient engagement and greater adherence to treatment plans. The technology is utilized in exposure therapy for the treatment of anxiety disorders and phobias, by creating controlled immersive environments for gradual confrontation of fears and anxieties. AR and VR are particularly useful in preparation for medical procedures, distracting patients exhibiting signs of distress before or during. But widespread adoption still faces challenges, including high hardware costs, limited bandwidth in remote areas, and regulatory complexities. XR therapy solutions must meet rigorous regulatory standards to ensure patient safety and data privacy, and navigating these regulations can be complex and time-consuming. Also, XR therapy's coverage by insurance is not guaranteed, making it just as inaccessible as current mental health treatments.

2ND YEAR ON THE LIST

IN-WOMB TREATMENTS

WHAT IT IS

In-womb treatments address fetal conditions pre-birth through surgery or medication. Early intervention, like repairing defects and treating anomalies, aim to improve outcomes for the deliverance of a healthy baby. Ongoing research and clinical trials seek to expand the scope of conditions that can be treated in utero.

HOW IT WORKS

Technology is making it increasingly feasible to treat fetuses while they're still in the womb, improving future health outcomes. In Boston, a team of doctors successfully performed a novel fetal surgery to treat a rare prenatal brain condition known as vein of Galen malformation, where blood vessels in the fetus' brain are improperly connected. A groundbreaking clinical trial at UC Davis Health delivered the world's first stem cell treatment for spina bifida in-utero. Scientists at UC San Francisco are pioneering in-utero stem cell transplants for the treatment of genetic disorders. A $2 million University of California, Davis project aims to cure Duchenne muscular dystrophy by editing genes using lipid nanoparticle injections in utero. The use of a fetoscopic approach for in-utero repair of gastroschisis is being tested in clinical trials at Texas Children's Hospital. And a student-led team at Johns Hopkins created a novel port system able to pierce through tissue, aiming to reduce the risk of membrane rupture during in utero surgery.

Advanced pharmaceutical and diagnostic technology is progressing toward use on pregnant patients and their fetuses. Trikafta, a drug treatment for cystic fibrosis administered to a pregnant mother, showed promise in reducing symptoms at birth. Treatments for the mother began at 24 weeks pregnant, and the baby was born without the bowel complications that had previously affected her two sons. The FDA has approved a blood test by Thermo Fisher Scientific that can identify pregnant women at imminent risk of severe preeclampsia, a leading cause of maternal mortality. The test measures the ratio of two proteins produced by the placenta, with up to 96% accuracy in predicting whether a woman will develop preeclampsia in the next two weeks. However the impact on outcomes remains uncertain as an effective treatment for this condition has yet to be developed.

WHY IT MATTERS

In-womb treatments are designed to address specific medical conditions or abnormalities in an unborn child. Fetal surgery may be performed to correct congenital anomalies, including procedures to repair neural tube defects, congenital diaphragmatic hernias, or twin-to-twin transfusion syndrome in identical twins, among others. Beyond surgery, in-womb treatments can involve the administration of medications directly into the amniotic fluid or through the umbilical cord to address certain fetal conditions, such as heart arrhythmias or anemia. But these treatments can be costly, raising questions about accessibility, health insurance coverage, and the financial burden on families. It also requires that expectant parents have access to comprehensive, unbiased information about the potential risks, benefits, and alternatives to in-womb treatments.

At the same time, advances in genetic testing promise earlier and more accurate prenatal diagnosis. Gene therapy research is exploring the possibility of in utero gene therapy to correct genetic disorders and inherited conditions before birth, while noninvasive prenatal testing based on cell-free fetal DNA is increasingly used to screen for chromosomal abnormalities. Future advancements include developing treatments for conditions like congenital heart defects, neurological disorders, and genetic diseases. This ongoing research into less invasive and safer procedures aims to reduce risks for both fetus and mother.

COGNITIVE AND NEURAL OPTIMIZATION

WHAT IT IS

There is a growing focus on optimizing brain performance by enhancing cognitive function and mental well-being. Nootropic foods and extended reality–based training exercises aim to stimulate brain function to boost neuroplasticity. While available research supporting proof of concept is limited, increasing demand has fueled scientific interest.

HOW IT WORKS

Researchers are beginning to report success in using XR technology to improve brain function and well-being. A study investigating virtual cognitive behavioral therapy for depression indicated that, on average, this approach through absorption training reduces stress in adults. The NeuroGrow Brain Fitness Program, a 12-week brain training program, has shown statistically significant improvements in cognitive tests and notable decreases in sleep decline and emotional symptoms in patients with ADHD and memory loss. A study published in Scientific Reports identified a positive correlation between a stronger sense of presence in VR environments and enhanced cognitive abilities, demonstrating the application of VR technology in brain training. Virtuleap, a VR brain training platform, entered clinical trials for its immersive experience featuring a telehealth tool for continuous patient monitoring. And the University of Texas at Austin has modified a Meta VR headset, by installing a noninvasive EEG device to measure brain activity during VR simulations.

There's also an increased interest in the growing nootropics market, valued at $2.5 billion in 2022. Nootropics are cognitive enhancers that aim to improve memory, focus, and creativity. According to a survey conducted by Mintel, 42% of US consumers have expressed interest in food and drinks to improve their focus and 72% of respondents showed interest in nootropics, by stating they either currently drink, have tried, or are willing to try beverages with cognitive-enhancing benefits.

WHY IT MATTERS

Brain health goes beyond a balanced diet, regular exercise, and adequate sleep: Cognitive functions such as memory, attention, problem-solving, and creativity require training and intervention for increased neuroplasticity. Psychological well-being, stress reduction, and emotional resilience play integral roles in overall cognitive health as well. Recent advancements have prioritized neurofeedback, emphasizing the practice of self-regulation. Some AR apps offer mindfulness and relaxation exercises that guide users through breathing exercises, meditation, and stress-reduction techniques, while others facilitate cognitive learning and skills-based training. Alternatively, nootropics have expanded beyond supplements and "smart drugs" as they are adapted into consumable food and beverages. While this market is expected to grow at a compound annual growth rate of 15.47% over the next 10 years, it is important to note there is limited scientific evidence to support their cognitive-enhancing properties. Though the science has not narrowed down a best approach, there is growing demand for treatment that optimizes brain performance, or at least extends the longevity of it.

MICROBIOMES AND HOLOBIONTS

WHAT IT IS

Our bodies are hosts to trillions of microbiota—communities of microorganisms that inhabit specific parts of our bodies, and as a whole, a microbiome. The holobiont concept defines the interconnectedness of a host organism and its associated microbiota, highlighting that as one ecological unit they function together so changes to one affect the other.

HOW IT WORKS

MIT engineers have developed a technology to probe the connections between the brain and the gut using fibers embedded with sensors and light sources. It allows for precise measurement of neuronal signals within milliseconds, providing insight into the gut-brain communication network. A group of researchers also successfully tested a smart pill, the size of a blueberry, in pigs for the diagnosis and treatment of bowel disease. The pill detects and reports key biological molecules associated with inflammation, converting the data to a wireless signal transmitted in real time to a user's smartphone. Developed by Seres Therapeutics, SER-109, the first oral drug designed to treat the microbiome has received FDA approval. Clinical trials showed promising results, with 88% of participants avoiding another C. difficile infection eight weeks after a single dosage. And Ayble Health launched an app that harnesses behavioral therapy techniques to treat chronic gastrointestinal conditions. The 15-week program retrains the connections between the mind and gut to ease GI symptoms.

WHY IT MATTERS

The human body is not just an individual organism but a complex ecosystem, where trillions of microorganisms co-exist and interact with the host's cells. The composition of the microbiome is unique to each individual and influenced by factors like diet, exercise, mental health, antibiotics, and environmental conditions. These concepts have stimulated research into how our environment, as it is related to these microorganisms, affects our bodies. As we gain a deeper understanding of the intricate connections of the holobiont, microbiome data will become a vital component of holistic wellness and medical assessments, enabling the development of personalized health care plans tailored to individual microbial compositions.

Recently research has focused on exploring the impact of gut microbiota on the interactions of gut-brain axis, as it is directly involved in the body's stress response. The aim is to develop treatments that target gut microbiota to influence brain function. Ideally the outcome will yield targeted interventions for metabolic disorders, autoimmune disease, and chronic stress and anxiety disorder, by harnessing synthetic biology to engineer microbes as "living drugs." Several start-ups have leveraged AI to analyze and translate microbiome data for personalized health recommendations and insights; others are developing microbiome-based therapies targeting immuno-oncology, gastrointestinal diseases, and neurological conditions.

7TH YEAR ON THE LIST

BRAIN-COMPUTER INTERFACES AND NEUROPROSTHETICS

WHAT IT IS

Brain computer interfaces (BCIs) establish a direct communication pathway between the human brain and computers, enabling body control without the use of the peripheral nervous system or muscles. For example, neuroprosthetics restore motor function by simply harnessing one's thoughts. Future advances seek to nurture human-machine symbiosis and redefine cognitive boundaries.

HOW IT WORKS

Varying in function and ability, BCIs are being used to restore speech and mobility. Electrodes implanted in the brain or worn outside the body can translate neural signals into commands for the prosthesis, allowing for natural and intuitive limb movement. One example is the groundbreaking bionic arm controlled by thought given to an amputee who lost both arms. Doctors at the Rehabilitation Institute of Chicago connected existing nerve endings from the shoulder to chest muscles via a nerve-muscle graft, enabling electrodes to receive through generated impulses. At UCSF, a neurosurgeon used a brain implant to capture the neural signals controlling facial expressions and speech. When combined with AI, this created a digital avatar that mimicked facial expression, allowing a participant who suffered from a stroke 18 years ago to communicate in almost real time.

Future advancements, like the BCI implant developed by Neuralink, aim to enhance cognitive ability by creating a direct connection with AI to reshape the human experience. Founded by Elon Musk, Neuralink is seeking volunteers for a six-year clinical trial. Its N1 chip is able to interfere with more than 1,000 brain cells and communicate via an end-user app that translates these brain signals into computer actions. In the meantime, noninvasive BCIs are being adopted into consumer technology. NextMind's EEG electrode, acquired by Snap for its AR glasses, was designed to decode neural activity to control smart devices.

WHY IT MATTERS

The once speculative domain of science fiction writers is now a tangible reality as computers increasingly contribute to the enhancement of both mental and physical capabilities. The emergence of BCI technology is actively shaping the potential of the human race. By redefining human computer interaction, BCIs open up new avenues for restoring sensory function and mobility to the physically impaired. Recent advancements have concentrated on neuroprosthetics; BCIs allow patients with damaged neural pathways to control prosthetics or assistive devices using their thoughts, restoring independence. However, sustained effectiveness and safety of implanted devices will require addressing the long-term impact, including tissue damage and sign degradation, on the nervous system. Many such devices are still in their trial phases, which has led to complex questions about long-term maintenance, upkeep, and support.

Increased investment and research highlights the applicability of BCIs beyond the physically and cognitively impaired. BCIs could amplify human capabilities and redefine the boundaries of human potential. Think Iron Man's ability to seamlessly interact with his environment and enhance his ability by manipulating AI and XR technologies. Advancements are seeking to improve the human experience by redefining mind control. However, the thought of achieving human-machine symbiosis is triggering fundamental fear about what is human and our ability to maintain privacy.

1ST YEAR ON THE LIST

PRECISION MEDICINE

WHAT IT IS

Precision medicine replaces the traditional one-size-fits-all approach by tailoring treatment and prevention to an individual's environment, lifestyle, and genetic makeup. Through precise and targeted genome editing, doctors can develop treatments that are either highly specific to each patient or to a disease, increasing efficacy and minimizing side effects.

HOW IT WORKS

The first CRISPR-based treatment for sickle cell disease and beta-thalassemia has received approval in the UK, and the US FDA may approve it soon. The Casgevy therapy, also known as "exa-cel," was developed by Vertex Pharmaceuticals and Crispr Therapeutics. For patients with sickle cell disease and beta thalassemia, both inherited blood disorders, the therapy prevents pain episodes and eliminates the need for regular blood transfusions respectively. The treatment involves editing a gene using CRISPR and infusing the modified cells back into patients. However, the cost, likely to be $2 million per patient, and the treatment's complexity pose challenges for accessibility. A task force led by Nobel Prize winner Jennifer Doudna proposes a mixed organizational model to lower the cost of innovative cell and gene therapies, with a goal of making them more accessible.

Researchers have shared preliminary results from a study that used CRISPR base editing on the PCSK9 gene in liver cells necessary for the production of low-density lipoprotein cholesterol. This study is evidence that editing a single DNA letter in the liver can have a clinical effect. Given these and similar advancements, scientists are also exploring CRISPR-based therapeutic approaches for complex diseases, like Alzheimer's, that are not considered genetic. Scientists at Duke University are testing an approach that aims to reduce the activity of the APOE4 gene, which is associated with an increased risk of Alzheimer's.

WHY IT MATTERS

The goal is more targeted health care by enabling doctors to predict how a patient will react to a drug and prescribe an individualized treatment. Precision medicine accounts for individual variations in a patient's genes, while considering the person's environment and lifestyle. It also lends to the exploration of disease biology, crucial for gaining insights into the causes of diseases and identifying potential targets for therapeutic interventions. In this context, precision medicine holds promise for expanding the scope of diagnostics and introducing innovative gene therapy treatments.

Gene editing is part of a broader revolution targeting the root causes of diseases, enabled by advancements in AI for increased efficiency, specificity, and data analysis. Researchers can modify genes associated with diseases to better understand their function. They can then develop drugs that specifically target these genetic mutations, potentially extending the lives of individuals affected by rare disease. But widespread adoption of precision medicine faces challenges related to the accessibility and affordability of whole genome testing, despite growing support from public health care systems. Efforts are underway to reduce costs through collaborations, new manufacturing models, and the development of "over-the-counter" or "off-the-shelf" therapies. However, the rapid progress and refinement of CRISPR gene-editing technology may expand its application to a wider variety of diseases and lower the associated costs.

1ST YEAR ON THE LIST

DESIGNING AND EXTENDING LIFE

WHAT IT IS

Breakthroughs in synthetic biology have ignited interest in designing and prolonging human life. Ethical considerations involving the altering of parenthood, mortality, and the intentional manipulation of human design are greatly influencing advancements.

HOW IT WORKS

While the idea of genetically modified babies remains widely debated, scientists continue to explore revolutionary methods of reproduction. EctoLife, the first artificial womb facility, is seeking to optimize genetic material, while addressing infertility and population decline. Biotech startup Conception is introducing a different approach; it's working to commercialize in vitro gametogenesis (IVG), the creation of human eggs from stem cells. The experimental technique could benefit women who have lost eggs due to cancer treatment, those unable to produce healthy eggs, and women with aging eggs.

Entrepreneurs, including Jeff Bezos (Altos Labs), Brian Armstrong (New Limit), Peter Thiel, Larry Page, and Sam Altman, have invested millions in the exploration of extending human lifespans, and possibly achieving immortality. One approach, "rejuvenate" blood, was inspired by studies at Duke University that extended the lives of old mice via blood transfusions from young mice. Though the study does not provide an antiaging treatment for humans, it hints that the blood of young mice contains compounds that promote longevity. Biotech company Rejuvenate Bio claims to have successfully used a reprogramming technique to extend the lifespan of mice. Adding three reprogramming genes to 77-year-old equivalent mice increased their lifespan by 7%. The technique involves resetting cells to a younger state, which has been the focus of significant research and investment as a potential anti-aging intervention.

WHY IT MATTERS

A race to immortality? From genetic interventions to rejuvenation therapies, the wealthy elite is rewriting the narrative of aging, turning it into a conquest rather than an inevitability. These tech moguls envision a future where age is just a number, and death becomes an obsolete concept. The convergence of Silicon Valley and life sciences has given rise to ambitious ventures seeking to unlock the secrets of longevity. As they pour resources into extending human lifespan, ethical concerns emerge, adding complexity to our understanding of death and the right to die, while intensifying the demand for health care and exacerbating social inequalities.

By harnessing CRISPR technologies to selectively modify the DNA of embryos, babies can be customized for desirable traits. The practice has been particularly controversial, raising ethical concerns like the potential for unintended consequences, long-term health effects, the loss of cell identity, and the exasperation of genetic disparities. Advocates champion the opportunity to eradicate hereditary diseases and unlock unprecedented human potential, while critics emphasize the ethical complexities and potential societal consequences associated with manipulating the fundamental building blocks of life. In this ethically charged arena, scientists instead look to overcome infertility challenges by providing a source of gametes independent of natural reproductive processes, offering new possibilities for fertility treatments.

PHAGES

WHAT IT IS

Natural predators of bacteria, phages regulate bacterial populations in the human body. With engineering, they also have enhanced ability to detect and attack bacteria. Though extensive research of phages is fairly recent, they show immense promise for addressing bacterial maturation and present a promising strategy to address antibiotic resistance, a significant global health concern.

HOW IT WORKS

Phages are viruses that specifically target and infect bacteria, offering a highly -targeted and precise therapeutic approach. An MIT student discovered that a protein on the phage's surface, capsid protein, sometimes activates a defense system known as CapRel during infection. This restricts the phage's ability to bypass the bacteria's defense mechanism, offering insights that further the understanding of how phages work. While they offer a highly personalized approach to combating drug-resistant bacteria, additional research is needed to understand how phages react to different individuals and bacteria. The Geneva University Hospitals and the University of Geneva successfully treated a patient suffering from an antibiotic-resistant chronic bacterial lung infection with phage therapy. The treatment was a last resort when the patient was unresponsive to continuous intravenous antibiotic therapy.

Researchers at ETH Zurich have developed a rapid test that detects a urinary tract infection using bacteriophages. The scientists identified the phages effective against the bacteria most common to UTIs and modified them to emit a light signal when the bacteria is detected within the sample in less than four hours. This method holds promise for immediate antibiotic prescriptions tailored to a patient based on the strength of light signals. With $2.3 million in seed funding, Parallel Health has introduced a custom phage therapy skin solution. The serum features phages customized to users for treating chronic skin conditions—but requires facial swab every six months to account for changing skin microbiomes.

WHY IT MATTERS

Drug-resistant infections are one of the most serious threats to global health, but bacteriophages offer a promising avenue in combating antibiotic-resistant bacteria. Researchers and health care professionals are exploring phage therapy as an alternative or complementary treatment. Phage therapy allows providers to practice precision medicine through customized treatments based on a patient's specific bacterial infection. Unlike broad-spectrum antibiotics, phages can be tailored to target specific strains of bacteria while minimizing impact to the body's beneficial microbiota. Though phage therapy is not a new concept, its resurgence in mainstream health care reflects the urgent need for innovative solutions to combat antibiotic resistance. Ongoing research aims to refine protocols and expand its application within the entire health care industry.

EXPANDING MEDICAL MIS- AND DISINFORMATION

WHAT IT IS

Misinformation and disinformation entail the spread of false information and the deliberate intent to deceive, respectively. Both fuel confusion and lead to poor health choices and trust erosion, which is especially dangerous during pandemics by hindering vaccine efforts. Social media and AI-driven communication accelerate the potential for an infodemic, excess of information, amplifying the dissemination of inaccurate information.

HOW IT WORKS

Researchers at Flinders University attempted to generate disinformation about vaping and vaccines using generative AI. Within an hour, they were able to produce over 100 misleading and deceptive blogs, images, and videos promoting health disinformation, highlighting the urgent need for government and industry guardrails to protect public health from the malicious use of generative AI tools. Social media sites have implemented policies to combat mis- and disinformation on their platforms through warning labels on false content, reducing the reach of such content, or removing it entirely. Despite enacting these policies, social media platforms have notably downsized content monitoring staff, risking their effectiveness. On TikTok Shop, merchants are defrauding consumers, publishing videos featuring deepfake doctors to deceive buyers into believing that health products are being promoted by medical professionals. These videos have garnered more than 10 million views, illustrating the deceptive power of disinformation and the extreme difficulty in deciphering between real and synthetic content. Amid security and privacy concerns, TikTok issued new community guidelines for the regulation of manipulated content. In the UK, YouTube has begun to validate health care professionals creating content on its platform. Applicants must meet strict criteria and confirm that they have an active medical license; when they're approved, their profile features a badge that verifies to users that the content comes from a reliable source.

WHY IT MATTERS

AI-generated content may seem like viral fun, but its role in perpetuating the infodemic has been rather damaging. In the era of the internet and social media, misinformation and disinformation tend to spread more rapidly, facilitated by the ease of access to a wide audience. Left unchecked, false narratives about diseases, treatments, and preventive measures can lead to fear and confusion. At the individual level, misinformation can lead to misguided decisions about treatment, vaccination hesitancy, and reliance on unproven remedies, exacerbating health issues. At the societal level, public health efforts are compromised as misinformation fuels resistance to evidence-based practices, resulting in delayed or inadequate care. Misinformation-driven health trends can also divert attention and resources away from genuine public health concerns, hindering effective allocation of resources. As demand increases for certain medications or interventions, shortages may arise and lead to escalating costs. Collaboration between health care professionals, policymakers, and technology platforms is crucial to curb the spread of false information online. Tackling misinformation requires a multifaceted approach that includes strategic communication strategies, media literacy initiatives, and responsible content moderation on digital platforms. For instance, social media platforms can make their algorithms more transparent, so users understand how content is promoted, to decide what information to take seriously.

SCENARIOS

A New Kind of High

Nanobots, initially designed for revolutionary medical applications such as targeting disease at the cellular level and repairing tissue damage, have found a new, unconventional use. Beyond their medical prowess, these tiny robots have entered a more controversial territory: cognitive and emotional manipulation.

This new application involves nanobots interfacing with a user's neurological system to manipulate emotional states and cognitive abilities. Once introduced into the body, these nanobots navigate to specific brain regions responsible for emotional regulation and cognitive processing. They can release neurotransmitters or alter neural pathways to induce a range of desired states, from heightened happiness and confidence to suppressed anxiety or sadness. The allure is potent: the ability to control one's emotional and mental state with precision, bypassing traditional therapeutic methods.

While initially seen as an effective measure to improve population mental health, users became increasingly dependent on nanobots for emotional and cognitive regulation, losing touch with their natural capacity to experience and process emotions authentically. This overreliance also raised significant concerns about the long-term impact on brain function and mental health. The distinction between artificial and genuine emotional experiences becomes increasingly blurred, leading to societal debates and ethical concerns about the nature of human experience in the age of advanced technology.

These developments inevitably lead to complex ethical and legal challenges. Regulatory bodies were hard-pressed to address issues surrounding consent, mental health implications, and the definition of personal identity in an era where emotional and cognitive states can be externally controlled. The widespread use of nanobots for nonmedical purposes challenged the understanding of human agency and authenticity, igniting a global discourse on the boundaries of technological intervention in human life and the fundamental aspects of what it means to be human.

IMPLANTS, PROSTHETICS, & WEARABLES

EMERGING IMPLANTS

WHAT IT IS

Scientists seek a more custom approach to implants. The focus is on bioabsorbable and biocompatible material, including nonhuman sources, to eliminate issues of body rejection. New in-body 3D printing techniques promise new levels of personalization. Manufacturing limitations, durability, and extended lifespan need to be overcome for successful development.

HOW IT WORKS

Implants are no longer just synthetic; increasingly, they're designed from biological material to meld seamlessly with the human body. At Northwestern University, researchers developed a biocompatible water-soluble implant designed to relieve pain without drugs and naturally absorb into the body after use. The device delivers targeted cooling—numbing nerves to block pain signals to the brain—and users can remotely activate the device and adjust its intensity. As 3D printing has evolved, it has revolutionized biofabrication and tissue regeneration. Researchers in Sweden developed a 3D-printed eye implant for cell-based therapy to treat diabetes. The device, only 240 micrometers long, was placed between the iris and the cornea: This location in the anterior of the eye is considered to be immune-privileged, allowing for the implantation of pancreatic cells without triggering an inflammatory response. In the pursuit of biocompatible material, xenotransplantation—implanting animal cells into a human—introduces a new dimension. Doctors at the University of Maryland completed the second successful xenotransplantation of a modified pig heart in a patient with end-stage heart disease, who lived for six weeks after surgery. Engineers from Duke and Harvard have created a unique biocompatible ink that can transform into various 3D structures inside the body by absorbing ultrasound waves. This innovation allows the ink to reach tissues, bones, and organs that were traditionally only accessible through surgical procedures.

WHY IT MATTERS

Biotech's influence on the health care industry has given rise to the volume and diversity of data outputs in the human body. Compared to wearable technology, implantable devices offer more precise data due to their reach within the body. However, as scientists are forced to consider the body's innate immune response, it has become critical to evaluate the materials used and how they are disposed of afterward. This is especially important as built-in sensors are increasingly incorporated for real-time monitoring and data transmission. One viable solution is potentially xenotransplantation. Through this technology, we may be able to overcome compatibility issues, as ongoing experimentation hopes to neutralize immune response to nonhuman organs. If successful, xenotransplantation could greatly expand the pool of available organs. However opinions on acceptance vary, as it raises concerns about animal welfare and disease transmission. The use of neurostimulation for enhanced function and monitoring is also generating extreme interest. The industry is seeking ways to harness or control brain function for improved health, like the treatment of pain without the use of opioids. Its continued focus on durability and extended lifespan could address the ongoing issue of "abandon-ware," implants that go unserviced after the fall of a neurotech company.

2ND YEAR ON THE LIST

EMERGING PROSTHETICS

WHAT IT IS

Innovations in prosthetic design aim to improve sensing capabilities with synthetic skins and novel surgical procedures. More broadly applicable, electronic tattoos are nearly invisible sensors attached to a user's skin, enabling wireless transmission of health information. Such advancements hope to preserve our natural appearance, avoiding an android-like resemblance.

HOW IT WORKS

Stanford University scientists developed an electronic skin (e-skin) that converts signals from pressure and heat sensors into brain signals. The e-skin mimics biological skin by detecting pressure or warmth, sending sequences of electrical signals to the brain. In trials the e-skin prompted a rat to kick its leg in response to pressure or heat, showcasing potential applications in improving prosthetics. BeBop Sensors has also unveiled RoboSkin, a flexible and thin tactile-sensing covering for humanoid robots and prosthetics to enhance their sense of touch.

The OPRA Implant System is the only FDA-approved bone-anchored prostheses in the US. NYU Langone Health conducted the first surgery using osseointegration, which involves permanently implanting a titanium device into the bone for direct attachment to an artificial limb. A practical substitute for conventional socket prostheses, benefits include enhanced mobility, increased comfort, and minimized pressure. The implant system results in improved surface perception, reduced residual limb pain, heightened stability, and greater utilization of prosthetic limbs.

At UT Austin, scientists developed a lightweight, wireless electronic tattoo for continuous heart monitoring outside clinical settings. Attached to the chest, the e-tattoo involves two sensors measuring electrical signals from the heart and acoustic signals for a comprehensive report of cardiac health by measuring cardiac time intervals.

WHY IT MATTERS

Advancements aim to make prosthetics feel and look more natural, helping people feel more comfortable in their "own" skin. Synthetic or electronic skin not only looks like real skin, but advanced sensing capabilities enable feeling through electronic stimulation. Biotech companies are harnessing neurostimulation for increased movement and sensory feedback. The departure from hyper-realistic bionic limbs aims to empower users by fostering a sense of identity and breaking down societal stigmas surrounding disability. Scientists are also exploring the design and surgical attachment of prosthetics, with a focus on enabling function that mimics the human body. Newly designed prosthetics and surgical techniques, like osseointegration, aim to achieve better integration with the human body. But accessibility remains a hurdle as prosthetics are often costly and options are limited, especially for people of color. Efforts to combine affordability, functionality, and individualized design are underway, recognizing the diverse needs and preferences of users.

With the rise in use and function of wearable technology, scientists are harnessing the understanding of skin function to develop advanced sensing technologies that can be discreetly and comfortably worn on the skin. Such sensors promise more accurate data and measurements of biomarkers; e-tattoos can potentially replace the need for multiple devices for continuous monitoring, while ensuring comfort and durability.

EMERGING WEARABLES

WHAT IT IS

The next frontier of wearable technology not only transcends the boundaries of convenience but ushers in a new era, where our daily experiences are interconnected with the advanced capabilities of these devices. Ultimately, this will shape the way we navigate and understand the world around us.

HOW IT WORKS

The AR smart glasses market is becoming more competitive. An Apple patent filing signals the development of smart glasses for daily use, featuring a digital crown for controls, heads-up display for notifications and music control, and AR capabilities. Meta, which already introduced smart glasses through a partnership with Ray-Ban, plans to release its first pair of smart glasses with AR display in 2027, accompanied by a neural interface smartwatch for control. While health monitoring capabilities in these AR glasses remain uncertain, ongoing research, such as Cornell University's sonar glasses, hints at potential features. These glasses, outfitted with micro sonar that can track the wearer's upper body movements in 3D through a combination of inaudible soundwaves and AI, could offer advanced tracking of physical and behavioral data.

Parallel advancements in concealed wearable technology concentrate on miniaturized devices. Humane, founded by ex-Apple employees, revealed the Ai Pin, aiming to simplify interactions by eliminating traditional interfaces. Although its initial release features limited health functions, such as scanning for nutritional information, the Ai Pin shows promise for future applications in detection and continuous health monitoring. MIT researchers have developed a wearable ultrasound scanner designed to attach to a bra, aiding in the early detection of breast cancer. And Stanford has a smart bandage that leverages wireless circuitry and electrical stimulation to monitor and accelerate wound healing, minimizing infection risks.

WHY IT MATTERS

The proliferation of wearables, driven by their ability to provide unparalleled access to personalized health insights, has led to a growing demand for inconspicuous devices that can either substitute for or be concealed within our clothing. Progress on smart glasses and AR-enabled devices suggests a future where technology seamlessly enriches our lives without imposing on our personal style or daily routines. These wearables offer a subtler and more user-friendly experience that encourages users to wear them consistently, facilitating the collection of long-term health data. While the primary focus of these devices is on enhancing user interactions, the uncertainty surrounding health applications is getting research attention. These devices indicate a move toward a hands-free, augmented reality interaction with the world, opening up new possibilities in preventive health care by providing individuals with unprecedented access to personalized health insights and continuous monitoring. The technology aims to positively impact consumer behavior by inspiring better habits and heightened awareness as they embrace these devices. Still, concerns about data privacy persist, and so do worries around data security and the potential misuse of personal information.

MATURE WEARABLES

WHAT IT IS

As wearables become more sophisticated, they offer unparalleled access to personalized health insights and environmental interactions, becoming indispensable tools for maintaining well-being. However, ongoing progress is rendering wearables unnecessary, as innovations aim to seamlessly measure individual health data without the need for external devices.

HOW IT WORKS

Apple's and Samsung's patent filings suggest a shift in health marker measurement through smart rings. While ongoing research targets improved capabilities, a noteworthy development is the OmniRing, a smart sensing ring by a Penn State team, leveraging XR. The device uses inertial measurement unit sensors to capture finger motion and photoplethysmography sensors to measure biomarkers. It was introduced with an open-source design to spur diverse applications. Simultaneously, companies like Baracoda aim to enhance wrist wearables. Its smartband, BHeart, with its "endless" battery, utilizes BMotion energy harvesting from motion, body heat, and sunlight, redefining self-recharging. Beyond traditional health metrics, Neurable's brain-sensing headphones and BitBrain's Ikon neuro-headband measure brain activity. Neurable tracks brain signals to respond to cognitive states, while Ikon, with smart textiles and EEG electrodes, measures brain activity during daily tasks.

As our wearables gain capabilities, there are instances where "invisible monitoring" is preferable. Toronto-based Xandar Kardian is deploying its radar technology in 50 US health care facilities, providing contactless vital sign detection. The XK300 sensor gauges macro (body motion), micro (respiratory rate), and nano (heart rate) vibrations, offering early indicators of potential medical events. Singapore's Alexandra Hospital uses a Smart Ward ecosystem, streamlining nursing with virtual management. Internet of Medical Things components include smart beds, patches for vital sign monitoring, AI food scanners, and smart glasses for tele-rounding and teleconferencing.

WHY IT MATTERS

Wearables have significantly evolved beyond basic activity trackers and health metrics, incorporating advanced features for comprehensive health monitoring. The trajectory suggests innovations to measure an extensive array of health markers, as these devices now integrate sensors to measure vital signs, detect anomalies, track brain activity, and provide real-time health insights that factor in lifestyles and environments. Simultaneously, wearables are evolving beyond passive data collection to actively inspiring healthy habits and decisions. This active engagement with users can have profound implications for enabling personalized and proactive health care, motivating individuals to prioritize their well-being. However, as wearables mature and enhance functionality, there is a potential paradox emerging. The same advancements that make wearables indispensable could also render them superfluous. Wearables may become so seamlessly integrated into our lives, offering continuous health insights and habit reinforcement, that the need for a distinct wearable device diminishes. Striking a balance between enhancing functionality and maintaining the relevance of wearables will be critical. As wearables continue to mature, the challenge lies in ensuring that they not only collect a wider variety of health data but also meaningfully contribute to individuals' well-being while avoiding redundancy.

RESEARCH

SYNTHETIC HEALTH DATA

WHAT IT IS

Synthetic health data is artificially generated health data that mimics real data properties without privacy risks. Coupled with machine learning, the application of synthetic health data accelerates research and clinical trials for the development of novel medications, treatments and therapies.

HOW IT WORKS

Already, companies are harnessing AI and machine learning to advance research. LabGenius' system automates the design, creation, and testing of antibodies, revolutionizing the antibody discovery process. Its machine learning algorithm designs antibodies to target specific diseases, and automated robotic systems build and grow them in the lab. The data is fed back into the algorithm, creating a closed-loop system. DeepMind has released a catalog of genetic mutations that can affect the function of human proteins. Developed using AlphaMissense, an AI that classifies missense variants, the model categorized 89% of all 71 million possible missense variants as either likely pathogenic or likely benign. This can accelerate research providing insights into the consequences of genetic mutations.

Generative AI also plays a pivotal role in creating synthetic data sets that closely resemble real-world data without compromising privacy. Snowflake's marketplace now offers access to synthetic data sets, including synthetic human face and financial data. This enables businesses to train AI algorithms and conduct tests and simulations while maintaining data confidentiality. Gretel has entered an exclusive agreement with AWS, providing access to synthetic data generation models and privacy tools. The program aims to enable teams to safely test, train, and fine-tune proprietary large language models using high-quality synthetic data designed to be private.

WHY IT MATTERS

Synthetic health data replicates the characteristics, patterns, and statistical properties of real health care data without the risk of compromising patient privacy. When "real data" is insufficient, synthetic data is invaluable for ensuring that research data is comprehensive. AI holds the potential to drastically reduce the time required for research and clinical trials, providing industries dependent on these processes with remarkable flexibility for product innovation. Using synthetic data, medical researchers are harnessing AI and machine learning for critical tasks. Faster drug development is facilitated by synthesizing data on drug performance, screening drug compounds, predicting potential side effects, and optimizing dosages. This can lead to overhead cost reductions, making treatments more affordable and accessible. Early and precise diagnosis is facilitated by simulating disease progression, anticipating risk factors, and predicting treatment resistance. In disease eradication efforts, synthetic health data supports containment and eradication strategies by modeling disease spread to identify preventative measures while protecting patient privacy. Through the analysis of large datasets, synthetic health data becomes a valuable tool for advancing therapy research, optimizing treatments, and accelerating the development of novel therapies for disease.

NEW TRIAL METHODS

WHAT IT IS

Traditional trials suffer from lengthy timelines—averaging 10 years—and significant costs related to the recruitment and retention of participants. Now, remote, virtual reality, and in-silico trials are viable options. The goal of faster development of novel drugs and therapies could be achieved through improved efficiency, accuracy, and speed of clinical trials.

HOW IT WORKS

Last May, the FDA released landmark guidance to encourage the use of remote clinical trials, which leverage digital tools to collect participant data remotely. The Decentralized Clinical Trials draft guidance advises on how to incorporate remote clinical trials safely and strategically for greater diversity in clinical trial populations, and shows a clear shift toward the use of technology for conducting clinical trials. And companies have seen success transitioning from hybrid intervention to remote clinical trials. In making the switch, GROWell's strategy yielded a study completion rate of 82%, as well as improved screen failure rates and increased task adherence. In-silico trials, on the other hand, aim to remove human involvement in clinical trials altogether through digital simulations, or digital twins. Nova-discovery, specializing in AI-driven in-silico clinical trial simulation, has successfully predicted the findings of the MARIPOSA Phase III clinical study through its jinkō platform. The predictive findings closely align with actual trial results, highlighting the potential of in-silico approaches for optimizing the development of innovative treatments. Accenture Ventures has invested in Virtonomy, a company specializing in data-driven simulations using digital twin technology for accelerated development of life-saving medical devices. Virtonomy's solution enables manufacturers to create model patient virtual environments for device testing, reducing costs and regulatory complexity.

WHY IT MATTERS

Recent innovations in clinical trials aim to reduce time-to-market, while improving or maintaining quality and minimizing drawbacks. Covid led to the emergence of app-based, remote trials, which showed promise in expediting them without compromising quality. Other clear benefits include increased accessibility: Remote trials enable broader participation across a wider demographic diversity. The digital aspect of remote clinical trials also allowed for streamlined data collection. The next generation of such advancements will be VR trials, which will offer researchers increased control over the trial environment.

But in-silico clinical trials—leveraging AI and VR—go even further, eliminating human involvement in clinical trials altogether. They use synthetic data and simulations to produce comparable results to the human trials, and could potentially cut trial durations in half. Regulators like the FDA are exploring ways to incorporate in-silico trial data into the drug approval process. Additionally regulatory frameworks are being developed to ensure the reliability and validity of in-silico trial results.

Remote, VR, and in-silico clinical trials are disrupting the traditional practices of the health care industry, which have been rigid and slow to change. Their streamlined processes will make trials more efficient and cost-effective, and drastically reduce the time it takes to bring new medical innovations to market. Accelerated trials and shorter cash flow timelines will transform the investment landscape, potentially allowing new entrants to compete without the conventional need for substantial capital. The decreased risk associated with trials may encourage companies to embark on ambitious and high-risk projects, leading to a new wave of innovations.

1ST YEAR ON THE LIST

LAB-ON-A-CHIP

WHAT IT IS

Lab-on-a-chip (LoC) devices are revolutionizing POC diagnostics by integrating sample preparation, testing, and analysis on a single microchip. LoCs are transforming how laboratory analyses are performed, offering portability and convenience, efficiency, and versatility.

HOW IT WORKS

Increasingly, one microchip can do it all. SiPhox Health's kit can test for 17 biomarkers, including inflammation, cardiovascular health, metabolic fitness, and hormone balance. Sold on a subscription basis, kits are $95 with a monthly membership that includes access to continuous glucose monitors and personalized biohacking tools. The company is also developing an at-home device.

At the University of Bath, researchers have developed a prototype virus diagnosis device. Called LoCKAmp, it uses LoC technology and can provide lab-quality results within three minutes. It employs reverse transcription loop-mediated isothermal amplification to multiply specific RNA sequences for virus detection. Originally developed to detect Covid, LoCKAmp can be easily adapted to detect other pathogens. And a new signal processing method for biosensors from University of California, Santa Cruz and Brigham Young University researchers allows for simultaneous detection of particles in both high and low concentrations. The technique could lead to the design of LoCbiosensors that can detect multiple analytes across vast concentration ranges simultaneously. The researchers used an optofluidic biosensor chip with fluorescence detection and a new signal processing method to accurately identify the concentration of different colored nanobeads in a mixture. The technology is being commercialized by Fluxus, a California-based medical device company.

WHY IT MATTERS

Also known as a microfluidic chip or micro total analysis system, LoC is an automated miniaturized laboratory system that enables multiple medical tests to be performed at once. Traditional laboratory analyses often involve large quantities of reagents and samples, contributing to high costs. By requiring smaller sample sizes for accurate analysis, LoCs significantly reduce sample size volumes, risks of contamination, and associated costs. Given their compact and portable nature, LoCs allow for rapid and real-time analysis due to short fusion distances within the microchannels. This enables point-of-care testing, making this technology invaluable in patient diagnostics and biopharmaceutical development. It's especially useful for developing countries, where high incidences of disease persist due to limited resources and proper facilities. Increased focus on patient-centric care means that we can expect to see an increase in consumer LoCs to supplement remote care. In research, LoC devices facilitate high-throughput screening and experimentation. Researchers can conduct multiple analyses simultaneously, significantly accelerating the pace of discovery in fields like genomics, proteomics, and drug development. This will contribute to advancements in understanding disease mechanisms and the development of targeted therapies.

1ST YEAR ON THE LIST

BODY-ON-A-CHIP

WHAT IT IS

Body-on-a-chip (BoC) technologies typically consist of microfluidic channels and chambers that contain manufactured biomaterials, allowing researchers to simulate the behavior of various tissues and organs. By mimicking the function and mechanics of an organ, they provide a potential alternative to animals for drug development and toxin testing.

HOW IT WORKS

The use of "on-a-chip" models aim to mimic the physiological conditions of organs to provide a controlled environment for studying various phenomena. Researchers at the University of Birmingham have developed a "vein-on-a-chip" model designed to emulate human veins, offering a unique platform for studying blood clot formation. This innovative device incorporates operational valves that simulate real vein mechanisms, coupled with a single layer of endothelial cells covering the vessel's interior. Similarly, a global team of bioengineers and immune-oncologists collaborated to create an immune-infiltrated kidney tissue model, specifically focusing on investigating the on-target, off-tumor effects of T-cell bispecific antibodies (TCBs). This model—known as an immune-infiltrated human kidney organoid-on-chip—enables the assessment of TCB impacts on kidney cells. Additionally, researchers at Boston University devised an organ-on-a-chip model replicating lymphatic vessels capable of targeting the ROCK2 protein to reverse lymphedema in mice. And biotech company Emulate introduced a novel feature to its liver-on-a-chip model—an adeno-associated virus (AAV) transduction application. This groundbreaking technology enables gene therapy researchers to efficiently and safely test the delivery of AAV vectors in a validated, human-relevant liver model, providing results within weeks rather than months. In a previous study, Emulate's liver chip accurately identified 87% of tested drugs known to induce liver injury in patients.

WHY IT MATTERS

BoC systems, often referred to as microphysiological systems, replicate the complex interactions of organs and tissues within a human body on a miniature scale. By simulating the interactions between different organs, BoC devices demonstrate how drugs will behave in the human body. BoCs offer faster, cost-effective, customizable, more ethical and safer alternatives to human or animal trials for biological research and development, and could transform the drug development process that heavily relies on animal subjects. The application of BoCs will improve the efficiency of drug screening, reduce the number of failed clinical trials, and decrease time-to-market. While BoCs hold immense promise for advancing drug development, challenges for adoption include standardizing protocols and regulatory frameworks that adapt to accept these models.

3D BIOPRINTING

WHAT IT IS

A rapidly evolving technology, 3D bioprinting involves the creation of functional structures that imitate the complexity of biological tissues and organs by layering living cells and bioinks. While 3D bioprinting holds tremendous promise, it has technical challenges to overcome, such as ensuring viability and functionality.

HOW IT WORKS

A team at Monash University has successfully printed neural living networks composed of rat brain cells that mature and communicate like a real brain, while University of Oxford researchers fabricated a two-layered brain tissue from 3D printing human neural stem cells. Through the use of a novel droplet printing technique, the tissue maintained its cellular architecture for weeks in the culture. This marks a significant advancement in the fabrication of materials with the structure and function of natural brain tissue.

At the University of Sydney, researchers developed a blueprint for advanced human lung models with the use of 3D structures grown from human primary cells: They built two different lung models, healthy and diseased, to study the therapeutic effectiveness of drugs. Scientists at the Terasaki Institute for Biomedical Innovation have made advancements in 3D bioprinting of native-like skeletal muscle tissues. They used a specialized bioink with microparticles engineered for sustained insulin-like growth factor-1 delivery, promoting mature skeletal muscle tissue formation and structural alignment for more effective regeneration. And a multidisciplinary team at Stanford University received a $26.3 million federal contract to bioprint a fully functioning human heart and implant it into an immunodeficient pig within five years. This approach uses patient-specific stem cells that will not require immunosuppression when transplanted into the same patient.

WHY IT MATTERS

3D bioprinting is revolutionizing traditional approaches to tissue engineering and regenerative medicine. By precisely depositing cells in a spatially controlled manner, bioprinters can fabricate functional tissues and organs unique to individual patients.

This has huge implications for organ transplants. According to the US Health Resources and Services Administration, 106,800 people are on the national organ transplant waiting list, while Centers for Disease Control and Prevention data shows only 6,000 organs on average are provided by living donors each year.

The customization of 3D bioprinting is relevant to reconstructive surgery and preoperative planning: Medical providers can create patient-specific implants to match exact dimensions and specifications. Additionally, the ability to incorporate multiple cell types and biomaterials in the printing process allows for the creation of tissues with enhanced functionality. In research, 3D-bioprinted tissues offer more accurate representations of human physiology than traditional 2D cell cultures. With these models, researchers can assess drug response and toxicity with greater precision, while reducing, or even eliminating, the use of animals for testing. The biggest challenge of 3D bioprinting is sustaining larger, more complex tissues. For implanted tissues or a larger size to survive, the tissues must be vascularized to ensure proper nutrient supply and waste removal. Researchers are exploring bioink formulations, printing techniques, and post-printing strategies to overcome these challenges for clinical validity.

QUANTUM'S EFFECT ON RESEARCH

WHAT IT IS

The processing power of quantum computers rivals traditional computers. Quantum computers process complex data and construct computationally intensive models at unimaginable scale and speed. With its ability to analyze vast amounts of data and explore numerous possibilities simultaneously, quantum computing is ushering a new era of computational capability.

HOW IT WORKS

Intel announced the release of Tunnel Falls, a 12-qubit silicon chip, only available to the quantum research community. This and other actions—like a recent collaboration with the Laboratory for Physical Sciences—demonstrate Intel's commitment to advancing quantum computing research and accelerates its potential application in health care. IBM unveiled the first health care–focused quantum computer in the US, installed at Cleveland Clinic. The IBM Quantum System One, part of a 10-year Discovery Accelerator partnership, utilizes quantum computing, AI, and high-performance computing to accelerate biomedical discoveries. Gero, a biotech startup focused on aging and longevity, used a hybrid quantum-classical machine learning model to interface between classical quantum computational devices. Its aim was to demonstrate the application of quantum computing to generate novel chemical structures in drug discovery. Insilico Medicine combined the functions of quantum computing and generative AI to explore the quantum advantage in small molecule drug discovery. The researchers substituted each part of MolGAN, an implicit generative adversarial network for small molecular graphs, with a variational quantum circuit. Insilico plans to integrate the hybrid quantum GAN model into Chemistry 42, its proprietary small molecule generation engine, to accelerate and improve its AI-driven drug discovery and development process.

WHY IT MATTERS

Long considered in the realm of science fiction, quantum computing is more realistic than ever. In a world characterized by rapid technological advancements, the incorporation of quantum computing offers significant implications for drug discovery, genetic analysis, and optimization solutions. Harnessing quantum computing could lead to rapid identification of novel drugs and therapies, recognition of genetic markers associated with disease, and customized treatment plans based on genetic makeup. From optimizing treatment plans to managing health care supply chains, quantum algorithms can quickly pinpoint optimal solutions. This efficiency can enhance the overall effectiveness of health care systems, ensuring better allocation of resources and improved patient care. For instance, its rate of computing holds potential in enabling widespread genome sequencing for tailored treatments based on a patient's genetic profile. While quantum computing in health care holds great promise, it is still in the early stages of development, as several technical challenges need to be addressed. These challenges include improving the stability and error correction of quantum computers, as well as developing algorithms tailored to health care applications.

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FINANCIAL SERVICES & INSURANCE

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TOP HEADLINES

Financial services are evolving towards a future defined by instant, seamless interactions and robust security.

01

Banks Battle to Keep Digital Pace Amid Tech Evolution

Financial institutions are finding it increasingly difficult to keep pace with the rapid evolution of technology despite ongoing efforts in digital transformation.

02

2023 Bank Failures Eclipse 2008, Signaling Shift to Megabanks

The fall of Silicon Valley Bank, Signature Bank, and First Republic Bank marked a more significant disruption than the 2008 crisis, creating uncertainty for regional banks.

03

Financial Firms Must Revamp KYC in Digital Identity Push

As digital identity technologies advance, financial institutions must overhaul "Know Your Customer" (KYC) policies to make banking interactions and transactions more fluid and secure.

04

Instant Payments Get Closer to Reality with FedNow's Launch

With the introduction of FedNow in 2023, the financial industry is one step closer to instantaneous payments and real-time financial processing.

05

Banking Infrastructure Enters Its Blockchain Era

Orchestration, routing, and data security are poised to become the most exciting battlegrounds in finance, driven by leading banks' innovative use of blockchain.

STATE OF PLAY

Financial services are at a crossroads: balancing tech investment and innovation for the long term with a positive experience today.

Financial services institutions and insurance providers are facing a pivotal juncture. Innovation has brought advances like instant payments, digital wallets, and open banking, yet it has also revealed the fragile infrastructure underpinning legacy systems. Though financial groups tout significant technology spending, brick-and-mortar branches are being rapidly closed leaving customers with fragmented services and a need for more consistent access. While many services still require in-person visits, call centers scale back as digital traffic surges, and systems suffer frequent outages.

Legacy financial organizations that are still struggling to modernize face an unpleasant reality. The digital transformation endeavors undertaken in the late 2010s are falling behind a wave of emerging capabilities: innovations like artificial intelligence and decentralized identity are already scaling, putting pressure on existing initiatives. Difficult decisions loom—whether to forge ahead with current modernization efforts, redirect budgets to trailblazing opportunities, or straddle both at the risk of diluted focus.

The imperative is clear: organizations must redesign technology stacks for a digital-first world, embrace agile innovation, and focus beyond quarterly results to make the long-term investments required to compete in the unfolding revolution.

KEY EVENTS

MARCH 10, 2023

Silicon Valley Bank Collapse
A bank run led to the government's seizure of SVB, the third largest bank failure in US history.

JUNE 5, 2023

Insurers Pull Out of California
State Farm becomes the second major insurer to pull out of California after Allstate announced its move in November 2022.

NOVEMBER 2, 2023

Sam Bankman-Fried Conviction
A jury found Sam Bankman-Fried, FTX founder, guilty of seven fraud and conspiracy charges.

APRIL 20, 2023

Markets in Crypto Act Approval
The European Parliament passed MiCA, which imposes requirements on crypto platforms, issuers, and traders.

JULY 20, 2023

FedNow Launch
The new Federal Reserve digital payments system will allow faster and cheaper cash flow.

LIKELY NEAR TERM DEVELOPMENTS

ACTION IS THE VERB FOR 2024

Financial institutions and insurance providers have spent years experimenting, pondering, and investigating new and influential technologies. To a great extent, the volatile market of the last several years created the optimal environment for thinking rather than doing. But 2024 will be different: New AI standards, scaled CBDCs, and forthcoming stablecoin regulations mark this year as a year of action. If financial institutions and insurance providers leverage this opportunity to make real progress on their technological investment, 2024 could be an inflection point for the industry.

Inflation (Should) Remain Steady

Current views suggest inflation will remain steady this year after cooling in late 2023. While Fed rate cuts will help maintain stability, rising housing and rental costs at the beginning of 2024 have put upward pressure on inflation, making it a space to watch.

US Election Outcomes

In addition to the presidential election, several senate seats are up for grabs in 2024 that could determine key outcomes in banking regulation over the next several years, particularly in Ohio, Montana, and California.

US Stablecoin Regulation

The Clarity for Payment Stablecoins Act of 2023 was passed by the House Financial Services Committee in 2023 in July, leaving many hopeful that the official legislation will pass sometime in 2024. The bill would regulate stablecoins like other financial institutions.

AI Standards Development

Top tech firms are participating in a joint effort led by the US Department of Commerce to create standards around the safe use of AI. While not purely FI-focused, the outcomes will likely inform how banks and insurance companies use the tech.

CBDC Launches

Several countries, including India, Brazil, and Singapore, have planned to launch CBDCs in 2024. While the scale and maturity of the efforts vary, 2024 should serve as a proving ground for whether CBDCs work in the wild.

Technology Investment

A recent survey showed that 92% of banks plan to increase technology spending in 2024. This investment will likely focus on data and AI, leading to strategic hires in specific areas of expertise. Hopefully, these investments will be practical and not experimental.

11 MACRO SOURCES OF DISRUPTION

| Technology | Media & Telecom | Demographics | Environment | Government | Public Health | Education | Geopolitics | Infrastructure | Economy | Wealth Distribution |

WHY FINANCIAL SERVICES & INSURANCE TRENDS MATTER TO YOUR ORGANIZATION

Expanding Distribution

Open banking frameworks and embedded insurance offerings enable financial institutions and insurers to deliver customized products through third-party platforms and apps. Integrating services with digital ecosystems can substantially expand consumer reach and acquisition without traditional sales and marketing costs.

Streamlining Onboarding

Emergent standards around digital identity verification, e-signatures, and digital wallets allow remote, paperless onboarding of new clients. Auto-validated customer data cuts administrative costs related to application reviews and background checks. These elements of streamlined onboarding enhance profitability through lower acquisition costs and faster account funding.

Optimizing Settlements

Blockchain-based settlement layers and real-time payment rails can reduce transaction times from days to seconds while lowering reconciliation expenses. Legacy back-office systems rely on complex intermediary clearing processes that amplify operational costs. Direct settlement improves cash flows.

Boosting Productivity

Sophisticated automation through AI and machine learning allows financial and insurance providers to optimize everything from underwriting approvals to claims adjustment. This digitization of manual review processes enhances accuracy and efficiency, reducing headcount and improving the effectiveness of human capital.

Ensuring Compliance

As personal data protection regulations emerge across jurisdictions, institutions require new capabilities around managing consent, data inventories, access controls, and surveillance systems. While temporarily increasing costs, data governance is table stakes for institutional trust and mitigates existential regulatory or cyber risk.

Virtualizing Operations

Digitization of customer-facing processes (like online banking apps) continues behind the scenes by virtualizing infrastructure. Transitioning from legacy systems reduces brick-and-mortar footprints, paper processing, manual labor, and associated multi-million dollar expenses.

OPPORTUNITIES & THREATS

Threats

Persistent and escalating cybersecurity hazards like hacking, malware, and phishing scams present substantial data and asset security challenges for financial firms housing sensitive customer information.

Emerging data privacy regulations in major jurisdictions require increased financial sector transparency and customer control, necessitating investments in continuous compliance efforts.

Disruptive financial technology startups promoting innovations such as digital payments, automated advisory, and blockchain are forcing banks and investment firms to adapt rapidly.

Fluctuating macroeconomic conditions, including interest rates, inflation, credit cycles, and potential recessions, significantly sway bank loan books and investment portfolios, posing economic stability risks.

Highly sophisticated fraud threats around identity theft, payment fraud, and more that cost the industry billions annually require ongoing detection and prevention efforts across financial institutions.

Opportunities

Exploring emerging identification technologies from outside banking could unlock avenues to create seamless customer identity verification in-person, online, and on the phone—enhancing user experience across all interaction channels.

Banks have opportunities to build on consumer demand for financial app features by integrating digital offerings like personalized recommendations based on data analysis—capitalizing on desires for more value-added digital wallet capabilities.

Pursuing practical AI applications that increase productivity and efficiency would allow financial institutions to adopt this technology strategically rather than just following the latest trend.

Employing behavioral insights and predictive modeling, including third-party data, to shape preemptive customer offerings aligned with needs could augment the precision of such analytics.

Future-focused infrastructure investment strategies enabling banks to support cutting-edge innovation can position them to stay ahead of evolving market expectations.

INVESTMENTS AND ACTIONS TO CONSIDER

1

Continue to invest in cybersecurity controls, AI-enabled systems for detecting fraud, upgraded data encryption, and refined access governance to comply with emerging privacy regulations and combat the increasingly sophisticated cybersecurity threats that manifest in the modern digital landscape.

2

Evaluate, in detail, all digital transformation efforts, programs, and initiatives against an updated comprehensive ten-year technology roadmap to ensure the modernization updates across business functions are keeping pace with the latest innovations in emerging technologies across industries.

3

Design and implement customer identity management transformation programs consisting of omnichannel capabilities across digital and in-person platforms. These will enable enhancements to identity verification processes that mitigate fraud while expediting customer onboarding and authentication.

4

Allocate additional budget, human capital, and resources towards augmenting predictive risk modeling analytics capabilities via alternative and synthetic data. This will facilitate preemptive adjustments within investment portfolios and other financial assets to mitigate vulnerability more effectively.

5

Provide substantial funding to build more flexible, agile core technological systems that simultaneously support integration with legacy and future cutting-edge innovations, facilitating quicker responses to rapidly shifting customer needs, competitor product offerings, and internal digitization goals.

6

Contemplate new product and service offerings that leverage emerging technologies to create more value for customers, or meet their needs for evolving risks. By integrating cutting-edge solutions such as artificial intelligence and blockchain, companies can enhance operational efficiency and introduce innovative risk management tools.

CENTRAL THEMES

Digital Fragmentation

Despite significant innovation funding, unfinished transitions from aging, on-premises systems have left customers facing intermittent access, frequent outages, and fragmented experiences. A focus on experimental innovation efforts rather than scalable customer-facing capabilities is often to blame for failed modernization efforts. The source of this fragmentation is decades of technical debt burdening financial institutions—sprawling, complex IT estates that have become exceptionally challenging to overhaul. The consequences are emerging at an accelerating pace: customer frustrations, brand erosion, outages during critical transactions, and tightening margins as costs escalate. As competitors increasingly offer integrated, omnichannel client service, outdated financial institutions run the risk of dissatisfied customers leaving for more advanced providers. The growing digital divide has expanded too far to ignore; near-term disruption seems inevitable as decentralized technologies ready a more seamless and integrated alternative.

Neobank Infiltration

Neobanks have narrowed the gap with traditional banks by targeting the digital shortcomings of established institutions. These entities, which capture nearly half of new account market share, leverage modern infrastructures, benefit from lighter regulatory frameworks, and disrupt key revenue streams in sectors like lending and payments. Younger cohorts make up most of their growth: 75% of new accounts originate from Gen Z or millennials, for whom the concept of a checking account has become indistinguishable from payment tools. Neobanks distinguish themselves by offering services such as bill management and negotiation, subscription management, credit score monitoring, and automated savings and investing, all of which are now considered standard features to many consumers. This evolution reflects how neobanks are reshaping the banking landscape, appealing to a tech-savvy, younger demographic and challenging the dominance of traditional banks.

Blockchain Rebound

After a period marked by speculative frenzy and significant fluctuations in Bitcoin's value, the blockchain and digital asset sectors saw a notable rebound with increased institutional interest in October. Despite volatile headlines, the steady enhancement of foundational technologies has progressed quietly. These advancements in global interoperability, execution reliability, and ecosystem tooling are setting the stage for sustained growth. A majority of the world's central banks are exploring central bank digital currencies (CBDCs) and digital asset strategies, signaling a shift towards mainstream acceptance. Innovations in multi-party compute, zero-knowledge proofs, and confidential computing are refining the balance between transparency and privacy. The emergence of an open, programmable, and borderless financial infrastructure suggests technology is no longer the main barrier to widespread adoption. However, significant policy challenges related to digital identity, compliance, consumer protection, and international coordination remain, keeping broader application to speculative trading. Mainstream use appears distant unless regulatory reforms align with technological advances.

CENTRAL THEMES

Cybersecurity Frontlines

As digital expansion accelerates, so does the proliferation of cyber threats. The shift from frequent, minor attacks to selective, high-stakes breaches has seen hackers exploiting vulnerabilities in legacy systems to monetize high-value data on the dark web. Enhanced security measures struggle against sophisticated ransomware that demands payments to unlock customer access, subtly undermining trust despite significant security investments. The relentless need for vigilance against the exploit kits hackers can deploy poses challenges for even the most robust security operations. Smaller entities face the tough choice of outsourcing security, potentially compromising control over vital systems and impacting financial health. Regulatory demands for risk management are essential yet can impede rapid responses to emerging threats. This constant, mostly invisible struggle for cybersecurity underscores the critical battle for system integrity and resilience, highlighting the complex dynamics in protecting digital landscapes.

Balancing Innovation and Policy

Emerging technologies are advancing rapidly, outstripping existing policy frameworks and oversight capabilities. The domain of cryptocurrencies and digital assets, with its complex custodial and transactional protocols, can create particular challenges for regulatory categories designed for conventional financial systems. Similarly, the trade-offs between explainability and performance in machine learning and artificial intelligence raise questions about accountability and fairness in systems. The gap between the pace of innovation and the capacity for regulatory oversight is widening, with central interventions potentially stifling the positive impacts of new technologies. The key to navigating this evolving landscape lies in enhancing organizational transparency and consumer understanding, which are as crucial for success as establishing universal standards. Creating the appropriate approach will require enhancing technological knowledge for business and policy leaders.

Soaring Customer Expectations

Today's digital transformation initiatives are failing to meet consumer expectations. Behind the scenes lie challenges such as integrating new databases, implementing advanced cybersecurity measures, and retiring old technologies. These necessary steps can lead to unfavorable customer interactions, such as systems that require re-identification and system outages and conversions. Today, almost all consumers expect fully personalized advice and consistent experiences across both physical and digital touchpoints. Even one negative interaction can prompt a consumer to consider switching to a different institution. To retain loyalty, brands must integrate physical and digital services and balance automated and human-centered interactions. Traditional brands may have an inherent trust advantage, yet this often relies on customer inertia. As consumer expectations escalate and more alternatives emerge, brands that cannot deliver experiences that fulfill their promises risk losing their competitive edge.

ONES TO WATCH

Alex Chriss, President and CEO of PayPal, for the company's leadership in digital payments, payment experiences, cryptocurrencies, and expanding global payment solutions.

Bradley Leimer, Co-Founder of Unconventional Ventures and Executive Director, Head of Fintech Partnerships and Open Innovation at SMBC, for his take on innovative technologies in banking.

Cathie Wood, Founder and CEO of ARK Invest, for her thematic investing advice and perspectives on leading technological innovation and shifts in finance, such as SEC approvals.

Dr. Dambisa Moyo; Member, House of Lords— sitting as Baroness Moyo of Knightsbridge; Investor, Board member, Author; for her thought leadership on macroeconomics and global affairs.

Daniel Schreiber & **Shai Wininger,** Founders of Lemonade, for their company's disruption of the insurance industry using AI and data analytics, reimagining claims and customer service.

Hiromichi Mizuno, former Chief Investment Officer of Japan's Government Pension Investment Fund (GPIF) and UN special envoy, for his work in innovative finance and sustainable investments.

Jack Dorsey, founder of Twitter & Block, for innovatively fusing social media with finance, significantly shaping digital communication and transactions across platforms.

Dr. Janet Yellen, United States Secretary of the Treasury, for her work leading the Treasury's policies and thought work around CBDCs, the future of money, and the evolution of payments.

Jason Keck, Founder and CEO of Broker Buddha, for transforming the insurance application and renewal process with agency management system (AMS) technology.

Ken Moore, Chief Innovation Officer of Mastercard, for his work leading the organization's perspective on emerging technologies like artificial intelligence and blockchain.

Kristo Käärmann, Co-Founder of Wise (formerly TransferWise), for the company's mission to cut through cross-border payment barriers, making transactions cheaper and faster.

Laura Drabik, Chief Evangelist at Guidewire, for her thought leadership and work on the factors shaping insurance's future, including technology and climate change.

Dr. Lisa D. Cook, Member of the Board of Governors of the Federal Reserve System, economist, and professor, for her groundbreaking work on economic policy and financial markets.

Max Levchin, CEO of Affirm, for his ongoing innovations, including developing anti-fraud efforts, co-creating the Gausebeck-Levchin test, and co-founding Affirm.

Michael Barr, Vice Chair of Federal Reserve for Supervision, for his work on regulatory proposals that would raise capital requirements and strengthen oversight for major banks.

Nick Molnar and **Anthony Eisen,** Co-Founders of Afterpay, for pioneering payment flexibility with their "buy now, pay later" service, reshaping retail finance and invisible payments.

Ricardo Lara, California Insurance Commissioner, for his navigation of the state's evolving environment and insurers' actions to decrease offerings due to climate-related risk.

Rodney Williams, Co-Founder of SoLoFunds and Co-founder and Chief Commercial Officer at LISNR, for the LISNR technology's work in contactless authentication and seamless transactions.

Rohit Chopra, Director of the US Consumer Financial Protection Bureau, for his polarizing but impactful perspectives on banking regulation and his work on open banking.

Sallie Krawcheck, CEO and Co-Founder of Ellevest, for developing a digital financial advisor for women emphasizing ethical investment and economic empowerment.

Sam Altman, CEO of OpenAI, for potential developments the company could lead in using generative artificial intelligence in financial services and insurance applications.

Shefi Ben-Hutta, Founder of Coverager, for tracking and analyzing the near-term developments and long-term factors shaping the insurance landscape.

Thasunda Brown Duckett, CEO of TIAA, for her leadership in finance, career-long advocacy for financial literacy and inclusion, and mission to expand retirement savings.

Vitalik Buterin, Co-Founder of Ethereum, for his revolutionary work in finance with blockchain, which is driving the growth of Decentralized Finance and smart contract applications.

BUILDING BLOCKS

11TH YEAR ON THE LIST

DIGITAL IDENTITY

WHAT IT IS

Digital identity is the online presence or persona of an individual, organization, or device, represented by uniquely identifiable attributes and used for digital interactions and transactions. While they used to be somewhat separate, the meteoric rise of digital interactions has caused one's "identity" and "digital identity" to become inextricably linked.

HOW IT WORKS

To date, digital identity is verified through mechanisms like multi-factor authentication, simple biometrics (such as a thumbprint), and digital or electronic signatures. However, new technological capabilities drive this space toward more seamless and invisible authentication. These capabilities apply across many industries but are essential for banking and financial services, where almost every interaction requires authentication.

CLEAR is preparing to roll out the CLEAR Lane of the Future in 2024, allowing CLEAR Plus Members to verify their identity with their face. Other venues are following suit: the Bank of America Stadium in Charlotte, NC, began using facial recognition in December 2023 in partnership with Verizon. Blockchain-based identities also provide an immutable record of one's identity. Sovrin is a blockchain-based decentralized identity network that enables verifiable, self-sovereign identities, allowing users to share only the information necessary for a transaction or interaction.

As more organizations implement digital identity measures, behavioral biometrics, which validate a person by analyzing things like typing speed or mousing patterns, will likely increase in popularity. While regulation may prevent US banks from implementing these measures, banks in Australia have come together to institute the Scam Safe Accord, which requires biometric verification for account openings.

WHY IT MATTERS

At the heart of digital identity technology is the ability to enhance security measures and mitigate the risk of fraud. Digital identity solutions offer robust verification processes, utilizing biometrics, encryption, and blockchain, among other technologies, to ensure that only authorized users can access sensitive financial information and execute transactions. Digital identity technology also simplifies the process of meeting regulatory requirements like Know Your Customer (KYC) and Anti-Money Laundering (AML) by streamlining the verification of customer identities and monitoring transactions for suspicious activities.

In addition to institutional benefits, customers expect seamless, secure, and rapid interactions with their financial service providers. Digital identity technologies could make interactions seamless, leading to entirely ID-free interactions. By simplifying the authentication process without compromising security, financial institutions can enhance customer satisfaction, foster loyalty, and attract new clients.

Implementing digital identity solutions can also lead to significant improvements in operational efficiency. Automated verification processes reduce the need for manual checks, thereby lowering operating costs and speeding up transaction times.

Digital identity technology is more than just a tool for enhancing security; it is a strategic asset that addresses a broad spectrum of challenges financial institutions face.

DATA MINIMIZATION

WHAT IT IS

Data minimization is a principle in data protection and privacy that emphasizes collecting only the data that is directly necessary and relevant for accomplishing a specified purpose. It advocates for limiting the amount of personal data gathered, stored, and used to the minimum required to achieve the objectives for which the data is processed.

HOW IT WORKS

Researchers are developing approaches that leverage technologies like fully homomorphic encryption (FHE) to help organizations meet data minimization standards. With FHE, data is encrypted so that third parties can perform analysis and operations on the encrypted data without ever having access to the unencrypted data. For example, a company could confirm an individual's identity through an FHE-based database without seeing, accessing, or storing personally identifiable information.

A similar approach, differential privacy, ensures that the privacy of individuals in a dataset is protected when statistical analyses are performed. It works by adding a certain amount of random noise to the data or the results of queries on the data, making it challenging to infer information about any individual within the dataset. The goal is to allow data analysts to extract useful aggregate information from a dataset without compromising the privacy of any individual. Differential privacy can be beneficial when implementing AI models to avoid having the model inadvertently learn or reveal sensitive information about individuals from the training data.

Companies are also addressing data minimization needs through consent management; however, this approach can fail if consent is obtained by requiring consumers to agree to a sharing policy they do not fully understand. Other relatively analog solutions include stricter access controls and regular data cleaning and deletion.

WHY IT MATTERS

Data minimization is crucial for financial institutions and insurance companies, especially with both federal bodies like the FTC and individual states enacting stricter data privacy regulations in 2023. These laws mandate limiting data collection and usage, aiming for compliance, enhanced security, and customer trust.

By adhering to data minimization, organizations can reduce the risk of data breaches, enhance privacy protections, and build trust with customers and users by demonstrating responsible data management practices. Data minimization practices, however, may stand in stark contrast to organizations' increasing use of AI: the concept of reducing or minimizing the amount of data an organization has, especially in its raw form, stands at odds with the need to build up a corpus of data to have a sufficiently reliable AI model.

In customer data lakes, reducing the amount of data held can benefit organizations; lowering data storage and processing needs can lead to streamlined operations and cost savings. Moreover, focusing on necessary data improves decision-making quality. Due to less data handling, simplified compliance helps navigate the complex regulatory landscape. Data minimization is strategic, balancing regulatory adherence with operational efficiency, security enhancement, and trust-building.

AI-POWERED CX

WHAT IT IS

Almost three-quarters of leaders have prioritized expanding AI across the customer experience. While CX has been a strong focus for financial services companies and insurers over the past decade or more, artificial intelligence serves as rocket fuel for these companies to further personalize their interactions and experiences.

HOW IT WORKS

The most common application of artificial intelligence to enhance CX is through chatbots or other servicing agents. WatsonX has developed advanced AI chatbots that use natural language processing (NLP) to respond to queries about anything from filing a claim to paying their bill.

While chatbots are an obvious choice for experimentation, other more sophisticated applications are beginning to emerge. Roots Automation, for example, has rolled out InsurGPT, a finely-tuned large language model trained on insurance data to parse documents, including submissions, claims notices, and customer or agent correspondence.

In other cases, companies implement AI in back-office operations to expedite customer decision-making, creating speedier experiences. In one example, Nationwide Insurance partnered with DigitalOwl, a tool that uses AI to quickly summarize vast stores of medical records, increasing the speed of life insurance underwriting.

Some new banking upstarts offer AI-based features like notifications and guardrails: cred.ai issues a credit card that limits your spending based on the amount of money you have in your linked deposit account. As you spend, money is set aside in your deposit account to ensure you can pay it off.

WHY IT MATTERS

The initial investment in AI technology can be substantial, covering both the technology itself and the training and restructuring needed to integrate AI into existing systems. Organizations may feel uncertain about the return on investment, especially since there is no past experience with these AI applications to guarantee improved customer experiences.

Ironically, while AI aims to personalize customer experiences, there's a risk of depersonalization if implemented incorrectly. Over-reliance on AI without human oversight can lead to customer experiences that feel generic or lack the human touch, potentially affecting customer satisfaction and loyalty.

As AI technologies such as chatbots and document processing systems handle more tasks traditionally performed by humans, there will be a decreasing need for a large customer service staff, affecting employment within the industry.

AI applications that are purpose-built for insurance will enable streamlining, automating, processing, and analyzing documents such as insurance claims and medical records. These applications will create operational efficiencies, reduce manual labor, speed up decision-making processes, and shorten the time required for services like insurance underwriting.

1ST YEAR ON THE LIST

AI-ASSISTED DATA MODELING FOR INSURERS

WHAT IT IS

AI-assisted data modeling is a game-changer for the insurance industry, driving significant advancements in risk assessment and fraud detection. By leveraging AI to analyze vast quantities of data, insurance companies can uncover nuanced insights and drive more accurate decision-making.

HOW IT WORKS

A patent application filed by Travelers Insurance in May 2023 outlines a solution to help reduce cargo theft using AI imagery analysis. In this solution, AI analyzes images or sensor data of cargo at various points in time. The system can identify theft, damage, or other loss events by comparing these data points. This approach allows for immediate detection of discrepancies, significantly increasing the chances of quickly preventing theft or recovering stolen goods.

Another patent from State Farm describes the integration of LiDAR (Light Detection and Ranging) and AI to advance spatial analysis, property management, and navigation. The patent encompasses creating and using 3D models to visualize home renovations, optimize object placement, design landscapes, locate utility lines, and manage commercial inventories. Additionally, it includes AI-based recommendations for interior design, generating new floor plans, and facilitating 3D navigation within buildings.

Solution providers are also developing products to help carriers improve their data analysis. Astera ReportMiner automates the extraction of information from unstructured documents, streamlining claims processing and improving underwriting decisions. It uses AI to efficiently identify and extract critical data points from formats like PDFs, TXT files, and spreadsheets.

WHY IT MATTERS

Insurers will have a more comprehensive view of potential risk by leveraging unstructured data sources.

While companies will need regulatory changes to implement AI into pricing, future applications could enable more accurate and dynamic premium settings by analyzing a more comprehensive range of variables, including new data types and patterns that traditional models may not capture. Such premium calculations would more accurately reflect the risk profile of policyholders, ensuring that pricing is both competitive and reflective of actual risk.

Similarly, although it would invite the same level of regulatory scrutiny, AI could significantly enhance the underwriting process by quickly analyzing complex data sets, including non-traditional data sources, to assess the risk associated with insuring individuals or entities. Improved data sets enable more accurate underwriting decisions and the potential for developing customized insurance products. Today, companies could leverage "lite" versions of AI into underwriting processes by ensuring the final decision sits with the human underwriter.

AI models can also predict claims' likelihood and potential cost, enabling insurers to allocate resources more efficiently and prepare for future liabilities. Automated claims processing powered by AI can also speed up the settlement process, reducing the time and cost associated with claims management. This application is more readily available today due to the lesser regulatory hurdles.

6TH YEAR ON THE LIST

SCALING CRYPTOCURRENCIES

WHAT IT IS

Financial services and insurance companies are integrating cryptocurrencies, leveraging their scalability for efficient products as well as new financial products, like crypto custody, digital asset protection, and efficient transactions. While this offers opportunities like access to new markets, it poses challenges due to volatility, regulatory uncertainties, and security concerns.

HOW IT WORKS

Beginning in 2021, some insurers, including Metromile and AXA, announced they'd accept crypto as payment, with Metromile claiming it is the first insurer to both accept payment and pay claims in crypto. But the list has not grown significantly since then, and the crypto winter and subsequent SEC crackdown highlighted the volatile regulatory environment surrounding cryptocurrencies.

In June, Arch Insurance authorized the Lloyd's of London coverholder Evertas to write up to $420 million on crime-related policies involving the theft of private keys and provide insurance on crypto mining hardware of up to $200 million, the highest in the industry. These new limits represent a significant increase from the previous single policy limit of $5 million from Evertas.

As of September, Deutsche Bank (in partnership with Taurus) joins a growing list of global banks that provide crypto custody services. And more banks may take on crypto custody if the regulatory environment eases. In early 2024, banking associations appealed to the SEC to reevaluate a regulation that requires banks to list crypto assets in custody as liabilities, which forces banks to allocate an equivalent amount of assets. The group argues that altering this regulation would decrease the concentration of risk.

WHY IT MATTERS

The ongoing scaling of cryptocurrency in financial institutions and insurance companies offers organizations new market opportunities, including expansion into new client segments and services. Some companies may begin offering services like those discussed, such as crypto custody, or may develop new innovative financial products that are faster, more efficient, or more cost-effective than traditional offerings.

Financial institutions may also begin implementing crypto-based offerings to streamline transactions or offer new features such as programmable payments or instant cross-border transactions. Crypto also allows for more dynamic funding and payouts, like flexible treasury services.

Financial institutions in this space must be mindful of the developing regulatory environment. While some guidance exists today, other crypto-based laws will be in play in 2024. Institutions must closely watch the evolving regulatory landscape to stay aware of shifting compliance standards or impacts on capital requirements, capital allocation, and risk concentration strategies.

2ND YEAR ON THE LIST

OPEN BANKING

WHAT IT IS

Open banking, the practice that provides third-party developers access to financial data through application programming interfaces (APIs), enables new apps and services while ensuring greater financial transparency. Over the past year, there has been a push toward standardization, particularly as the EU's awaited Payment Services Directive 3 (PSD3) has finally passed.

HOW IT WORKS

In mid-2023, the passage of PSD3 brought renewed life to the open banking discussion. Like its predecessor, PSD2, the directive creates rules about the security of electronic or digital payments, creating uniformity across the EU—a critical element for the success of open banking.

One new patent application from Mastercard introduces a system that improves how payments are routed, focusing on increasing the chances that payments go through successfully. By examining details like the account holder's information and the transaction amount, the system calculates a "likelihood of success" score for each payment. This system can handle accounts held across different banks, calculating a success score for each account. It can also split a payment across multiple accounts, assessing the best distribution to ensure the payment goes through.

Visa is addressing consent management, another critical element of open banking. In one of their most recent patents, they introduced a system that automates user consent management for data sharing and actions taken on their behalf, enhancing privacy and control. When a request for user data is made, the system prompts the user for consent and, upon agreement, records this consent in a secure, immutable ledger. This process ensures that user data is only shared with permission and that all transactions are transparently logged for auditing.

WHY IT MATTERS

Open banking allows third-party providers to access financial data via APIs, fostering innovation and competition. As fintech startups introduce innovative products with this technology, financial institutions and insurance companies must adapt their offerings to compete. This environment encourages the development of tailored financial solutions that meet individual customer needs.

Some innovations may center on personalizing the customer experience. Access to comprehensive customer data enables financial institutions and insurance companies to offer personalized services. They can provide more accurate financial advice, better lending terms, and policies that closely match individual risk profiles. This data integration also simplifies application processes, improving customer satisfaction.

The sharing of customer data raises significant data security and privacy issues. Institutions will need to invest in strong cybersecurity measures and comply with data protection regulations to protect customer information. In addition to security measures, open banking mandates adherence to complex regulations, requiring significant updates to systems and processes. Financial institutions must ensure APIs comply with data sharing and security standards, facing challenges in integrating new technologies and managing third-party partnerships. This level of security will necessitate continuous investment in compliance and technology to navigate the open banking landscape effectively.

SCENARIOS

What if open banking evolves into a DeFi hub model?

By 2035, the banking sector has embraced the decentralized financial hub model, marking the next evolution of open banking. This transformative shift is underpinned by the widespread adoption of blockchain technology and cryptocurrencies, seamlessly integrating decentralized finance (DeFi) platforms into traditional banking services. This model revolutionizes how customers interact with financial services and introduces new complex regulatory implications.

In this evolved open banking ecosystem, banks function as secure interfaces between customers and the vast array of services offered by DeFi platforms. They facilitate lending, borrowing, and trading without central intermediaries, leveraging smart contracts to automate and secure transactions. This democratization of financial services extends open banking principles beyond mere data sharing, enabling a fluid exchange of assets and financial services across a decentralized network.

Regulatory bodies have responded to this shift by developing a new framework that ensures these decentralized services' security, transparency, and fairness. Financial institutions and other custodians or organizations that have cryptocurrency on the books must comply with smart contract auditing. These new rules ensure contracts operate as intended and look for code bugs that could alter outcomes. Regulators have also implemented interoperability standards to facilitate seamless interaction among blockchain networks and financial systems, ensuring that DeFi services can integrate with the broader financial ecosystem without compromising security.

This model represents a significant shift in financial services architecture, where regulatory compliance, innovation, and customer empowerment are intricately balanced. It heralds a future where financial services are more accessible, efficient, and secure, driven by the collaborative efforts of banks, regulatory bodies, and the DeFi community.

SEAMLESS INTERACTIONS

3RD YEAR ON THE LIST

FRICTIONLESS PAYMENTS

WHAT IT IS

Frictionless payments streamline transactions by minimizing user effort, creating a seamless experience. This approach, which includes invisible and embedded payments, integrates or automates the payment process within user interactions, enhancing convenience and efficiency across various platforms and services.

HOW IT WORKS

Block, the parent company of Square, CashApp, Afterpay, and other popular paytech companies, is attempting to make payments more accessible with one of their new patents, which describes a system that integrates payment and content provider platforms to make accessing digital content easier and more secure for users. The system also uses machine learning to personalize content recommendations and improves security by minimizing the need for users to enter sensitive information.

Israeli payment firm Nayax is creating a method for making digital payments using a web browser instead of a permanent digital wallet app. Users receive a URL via text message that, when clicked, installs a temporary digital wallet on their mobile device to complete a transaction. This wallet communicates with payment terminals using the device's NFC technology and is automatically deleted along with any payment information after the transaction, enhancing security.

Visa has introduced a method for embedding payment tokens directly into digital photos and other media metadata. This setup links each image to the copyright owner's account, allowing for easy and secure purchasing of media by embedding all necessary information, like price and copyright details, within the photo. The embedded data eliminates the need for intermediaries and simplifies buying and selling copyrighted images, ensuring copyright owners are directly compensated for their work through a seamless transaction process.

WHY IT MATTERS

Financial institutions, payment providers, and insurance companies can use the rich data from frictionless payment transactions to develop personalized financial products and services. Banks can leverage analytics to understand customer preferences and behaviors, offering tailored advice, personalized loan and credit options, and customized savings plans.

Insurance companies could leverage this technology to streamline the claims process, making it as frictionless as the payment systems themselves. Automated claims processing could significantly reduce processing times, improve accuracy, and enhance customer satisfaction.

Banks will face a growing demand from businesses for digital payment solutions that can integrate seamlessly with their retail operations. This demand includes the capability to process transactions smoothly and provide data insights, fraud prevention, and compliance with security standards.

The shift towards frictionless payments may alter traditional revenue streams for banks, particularly in transaction fees, as the competitive landscape could pressure fees downwards. But there is also potential for new revenue streams through value-added services. Banks need to rethink their revenue models to adapt to the changing dynamics.

3RD YEAR ON THE LIST

INSTANT PAYMENTS

WHAT IT IS

Instant reconciliation enables card issuers and merchants to swiftly balance accounts while cardholders enjoy the immediate reflection of transactions in their bank accounts. Similarly, insurance policyholders are coming to expect rapid claim payments, mirroring the accelerated pace of virtually every other aspect of modern life.

HOW IT WORKS

The Federal Reserve launched FedNow in July 2023, a real-time payment service that enables instant bank-to-bank transactions. This service aims to support faster and more efficient payments across the financial landscape, offering continuous availability for immediate settlement.

In competition with FedNow, Mastercard has expanded its partnership with The Clearing House to further the adoption of instant payments. New aspects of the partnership aim to identify additional instant payment use cases for consumers, businesses, and governments. The RTP® network, which currently includes 487 banks and credit unions, faces increased competition from the Federal Reserve's FedNow.

Launched in 2021 with seven initial banks, SWIFT Go has rapidly expanded its reach, now encompassing over 600 banks across 120 countries. Impressively, 85% of transactions processed through SWIFT Go are completed in less than three minutes. SWIFT Go enhances the speed of international payment processing, enabling banks to provide competitive alternatives to fintech solutions.

Currently, payments initiated on one rail must travel and settle across the same rail, creating walled gardens. For real-time payments to expand, the industry will need interoperability between rails.

WHY IT MATTERS

Real-time reconciliation could improve risk management by immediately detecting discrepancies and fraud. In traditional systems, the lag between transaction initiation and reconciliation can create windows of opportunity for fraudsters. Instant reconciliation closes these gaps, enhancing the security of financial transactions and protecting against financial losses.

Reducing overage fees through instant reconciliation may present a shift in revenue streams for banks, necessitating banks to re-evaluate their revenue models. Institutions may need to explore alternative sources of income, such as offering premium account services, investing in customer loyalty programs that encourage more extensive use of banking services, or introducing innovative financial products.

Leveraging instant reconciliation can differentiate a bank or insurance company in a crowded market: more than half of customers today say they'd switch insurers to access instant digital claims payments. This strategic advantage can attract new customers looking for transparent, customer-centric experiences.

Instant reconciliation improves operational efficiency, leading to faster settlement times and improved cash flow management, and allows banks and financial service companies to allocate resources more effectively. In Property and Casualty insurance companies, payment processing accounts for over a quarter of operating costs, with paper checks costing orders of magnitude more than a digital payment.

2ND YEAR ON THE LIST

BETTER DIGITAL WALLETS

WHAT IT IS

Digital wallets are virtual platforms that store payment information and other identifying credentials, offering seamless, secure, and fast payment options. They continue to evolve, incorporating advanced security features and expanding usability across global marketplaces, enhancing user convenience and financial accessibility.

HOW IT WORKS

Several companies, including Visa and Capital One, are working on developing solutions that improve the security of digital wallet provisioning. These solutions often include secure methods for adding or linking financial instruments to third-party digital wallets via one-tap contactless card authentication and utilize cryptograms to verify user identity and authenticate transactions.

Visa is also developing a novel approach to addressing the limitations of conventional payment systems, where a payment token is bound to a single card. The company is proposing the connection of a single token to multiple user accounts, which would enable the aggregation of credit limits from multiple cards for a single transaction. Their approach includes the generation of a virtual card which is associated with multiple accounts.

Finally, in early 2024, Visa launched Visa Commercial Pay, a new B2B payment solution aimed at businesses, incorporating features like corporate virtual cards for employees' digital wallets (e.g., Apple Pay, Google Pay) to allow detailed management of expenses with set limits and merchant specifications.

Major wallets like Apple and Google provide support for non-payment information, like ID and insurance cards. In mid-2023, Google Wallet announced new features to support passes with barcodes or QR codes, health insurance cards, driver's licenses, transit passes, and company IDs.

WHY IT MATTERS

Digital wallets make transactions faster and easier, encouraging impulse buying and attracting a broader customer base comfortable with digital payments. A study revealed that digital wallet users spend 31% more on average than non-users across all purchase types. This significant increase in spending among digital wallet users, especially Millennials and Gen Z, highlights the growing influence of digital wallets on consumer purchasing behavior, suggesting that these platforms facilitate transactions and encourage higher expenditure.

Businesses benefit in other ways from digital wallets; compared to traditional payment methods like credit cards, digital wallets often have lower processing fees, reducing business costs. Digital wallets also provide businesses with valuable data on customer purchasing habits, enabling targeted marketing and personalized offers. Companies can also integrate their loyalty programs with digital wallets, making it easier for customers to collect and redeem rewards, enhancing customer engagement.

Consumers now expect to be able to pay with a digital wallet. These tools offer convenience and ease to consumers and often have features that allow users to track their spending and manage their finances more effectively. As they become even more ubiquitous, younger generations are becoming used to carrying only their phone, reducing the use of physical wallets.

1ST YEAR ON THE LIST

TRANSACTIONS FROM ANYWHERE

WHAT IT IS

Technology is revolutionizing commerce by leveraging algorithmic purchasers and other features that extract data directly from vehicles or other sources and process transactions without traditional secure elements. These innovations enable consumers to engage in seamless and secure transactions from anywhere.

HOW IT WORKS

Mastercard is developing a solution to simplify in-vehicle purchases, connecting a vehicle's computing system with merchant payment systems. It introduces a token that contains details about the user's payment account, the car, and a biometric identifier. This token allows the vehicle to initiate transactions, verifying payments by matching token details with the user's biometric data. It streamlines the payment process, especially for purchases made without leaving the car.

Mastercard has also filed a patent for digital payments using natural language inputs. It enhances user verification by employing authentication factors, including biometrics, device location, and transaction history, to confirm user identity. The system leverages server technology to interpret user commands for scheduling payments, authenticate the user through these multifaceted checks, and efficiently carry out transactions.

Zero-knowledge proof (ZKP) is a way of sharing that something is true between two parties without revealing any extra details about why it's true. Companies use a feature of ZKP, called succinctness, to create more efficient blockchain systems known as ZK Rollups which enable blockchains to handle a vast number of transactions. ImmutableX, a ZK Rollup built on the Ethereum blockchain, supports the economies of video games. Before ZK Rollups, creating real-time, blockchain-based economies and gameplay experiences was impractical because of slow transaction times and high costs.

WHY IT MATTERS

For banks and paytech companies, seamless in-vehicle transactions and enhanced digital payments using natural language inputs and blockchain scalability open up innovative avenues for service delivery and revenue generation. Banks can tap into new markets by integrating their services with vehicles, offering customers the convenience of conducting transactions on the go.

This technology will also require robust security measures to protect sensitive biometric data and comply with stringent data privacy regulations. Adopting zero-knowledge proof and blockchain technologies like ZK Rollups could further streamline transaction processes, making them more secure and efficient, thus bolstering trust in digital banking services.

On the insurance front, blockchain's transparency and security features could revolutionize claims processing and fraud prevention, offering a more efficient and trustworthy system. While the example here discusses data in vehicle settings, this technology will undoubtedly be applied to other settings too, expanding the availability of high-fidelity real-time data for insurers.

The evolution of vehicle-based commerce could lead to new cyber products for original equipment manufacturers (OEMs), especially if the OEMs are housing or storing the data. These companies may require additional coverage associated with digital transactions, data breaches, and even identity theft related to biometric data.

SCENARIOS

SCENARIO YEAR 2035

What If Invisible Finance Enables Undetectable Fraud?

By 2035, the financial ecosystem, once praised for its innovation and security, faces a significant challenge. The "Invisible Finance Revolution," with its digital IDs, biometric checks, and automated transactions, is now vulnerable to data poisoning. This shift from conventional financial oversight has allowed cyberattacks to corrupt our AI systems, leading to distorted financial services. Fraudulent transactions and false insurance claims are rising, exploiting the once-secure blockchain technology.

The problem is exacerbated by our over-reliance on the system's reliability. The absence of friction in transactions led to an absence of vigilance: the convenience of not having to manually verify transactions has become a significant weakness, with financial irregularities often going unnoticed. Financial institutions, previously considered protectors of this digital space, are now struggling to fix these security breaches. Even with advanced encryption and fraud detection, they find themselves outpaced by these threats, shaking public trust in the financial system.

The current crisis highlights the downside of a frictionless financial world. The lack of transaction scrutiny has opened up significant security gaps. This situation serves as a reminder of the importance of balancing the embrace of new technologies with robust oversight and flexible security strategies. The idea of an invisible, effortless finance system has shown the importance of reevaluating our dependency on such technologies.

GOVERNANCE

RISING CYBER RISK

WHAT IT IS

Amid digital transformation, banks and insurance companies face escalating cyber risks. Cyberattacks, from data breaches to ransomware, threaten financial stability and customer trust. Enhanced cybersecurity and regulatory compliance are essential to protect sensitive data and maintain sector integrity.

HOW IT WORKS

In July 2023, a JPMorgan Chase Zelle outage affected over $2 billion in daily transactions and raised concerns about the resilience of banking systems. The incident, marking the second major Zelle glitch in six months, underscores the challenges of real-time payments and the urgent need to modernize core banking infrastructures to ensure reliability and trust in digital financial services.

In early 2024, stock-lending platform EquiLend was hit by a ransomware attack by LockBit, disrupting its operations that handle trillions of securities transactions each month. LockBit, a ransomware group, sought to negotiate a ransom for unlocking the systems.

In a recent patent application, JPMorgan Chase introduced a sophisticated method that leverages secondary identification information and electronic device identification to authenticate transactions, significantly enhancing identity theft protection. The importance of identification technology has only increased over the past year, as numerous financial institutions were hit by a wave of AI-powered deepfake technology in financial fraud, where voice deepfakes were increasingly used in bank scams and imposter schemes, tricking individuals and financial institutions.

WHY IT MATTERS

As cyberattacks grow more sophisticated, with AI-powered deep fakes and ransomware, financial institutions must invest in real-time threat detection and response systems. The introduction of advanced authentication methods, like those by JPMorgan Chase, marks a significant move towards fighting identity theft and financial fraud. Multi-factor authentication, biometrics, and device identification enhance transaction security and protect against fraud.

Recent cybersecurity incidents, including the JPMorgan Chase Zelle outage and the EquiLend ransomware attack, underscore the vulnerability of financial systems. Modernizing banking infrastructure to be resilient is crucial for minimizing operational disruptions and boosting customer confidence in digital finance.

The evolving nature of cyber risks has also prompted changes in regulatory frameworks. Financial institutions and insurance companies must review their policies regularly to ensure ongoing compliance with current and future regulations. Educating customers on cybersecurity and the risks of deepfakes will also play a key role in building a secure financial ecosystem.

The evolving nature of cyber threats could make it difficult for insurers to assess risks and price their products accurately. This uncertainty in underwriting can lead to mispriced policies, affecting the profitability of insurance companies.

1ST YEAR ON THE LIST

GLOBAL CRYPTO REGULATION

WHAT IT IS

Cryptocurrency regulation varies globally, but many nations are working to pass regulation, striving to balance investor protection, financial stability, and innovation. Efforts aim to address risks like fraud while embracing digital currency opportunities, but the borderless nature of crypto creates a complex regulatory patchwork.

HOW IT WORKS

The UK government plans to enact cryptocurrency regulations within six months, to enhance consumer protection and foster ethical innovation, fulfilling promises made by Prime Minister Sunak during his 2022 campaign. The regulations are expected to include guidelines for crypto exchanges, trading platforms, and custodians under traditional financial services rules.

US regulation over crypto came in the form of SEC enforcement in 2023, when the commission filed five high-profile lawsuits against major crypto companies. The Clarity for Payment Stablecoins Act of 2023 was passed by the House Financial Services Committee in July of 2023, leaving many hopeful that the official legislation will pass sometime in 2024. Broad-sweeping crypto regulation is unlikely in the US due to polarization in Congress and election year dynamics, but the industry is still working to prepare for potential incoming laws.

The Monetary Authority of Singapore (MAS) announced a new regulatory framework for stablecoins and their issuers, focusing on single-currency stablecoins pegged to the Singapore dollar or any G10 currency. Essential requirements include ensuring value stability through asset reserves, maintaining minimum capital, allowing redemption at par within five business days, and making necessary disclosures to users. This framework aims to safeguard financial stability and investor protection, distinguishing MAS-regulated stablecoins for easier identification by users.

WHY IT MATTERS

Financial institutions and insurance companies will have to navigate this complex regulatory environment for at least the next several years until things begin to align. The best practice is to develop operations around the strictest environment to ensure global operations remain compliant and prepare for forthcoming regulations. For example, financial institutions serving multinational companies must ensure their clients are compliant across their jurisdictions.

The ability to transact across borders using cryptocurrencies presents opportunities and challenges for banks and insurance companies. Cryptocurrencies can facilitate faster and cheaper international transactions by bypassing traditional banking networks and exchange rate complications. However, this also introduces regulatory complexities regarding jurisdiction and compliance with disparate international laws.

As regulatory clarity improves and institutions increasingly adopt cryptocurrencies, their usage will likely rise, bringing new or escalating risks. These include market volatility, cybersecurity threats, and operational risks, such as the safe custody of digital assets. Insurance companies, in particular, need help with underwriting policies for crypto-related risks due to the technology's lack of historical data and rapidly evolving nature.

11TH YEAR ON THE LIST

ALTERNATIVE CREDIT SCORING

WHAT IT IS

Alternative credit scoring represents an approach to evaluating an individual's creditworthiness that diverges from traditional methods. It incorporates a broader spectrum of data, including utility bill payments, rent, bank account information, and even patterns of digital interactions, providing a more holistic view of a person's financial behavior.

HOW IT WORKS

Credolab employs a novel approach to credit scoring and financial inclusion by leveraging privacy-consented, permissioned smartphone and web data. Their technology, which avoids AI, focuses on user behavior and anonymized metadata to predict creditworthiness, aiming to reduce onboarding friction and expand financial services to underserved populations. Credolab partners with companies like Provenir and TransUnion to enhance financial inclusivity through alternative data and behavioral analysis.

A new credit scoring model has identified 2.7 million new potential home buyers, unlocking a $1 trillion opportunity for lenders. VantageScore's latest model, required by regulators by 2025, expands access to credit by including underserved markets. The model, which has been used since 2017 by over 3,000 financial institutions, improves predictive accuracy using non-traditional data, benefiting consumers with limited credit histories or who are new to credit.

Pagaya leverages AI and alternative data to enhance credit decision-making, promoting financial inclusion. Through analysis of extensive data points, Pagaya provides recommendations for borrowers who may not meet traditional FICO scores, benefiting those with limited credit histories. Working with partners like TransUnion, Pagaya offers a more holistic view of creditworthiness, significantly impacting underserved communities and facilitating access to financial products for millions.

WHY IT MATTERS

Alternative credit scores enable financial institutions and insurance companies to tap into previously inaccessible segments. By considering factors beyond traditional credit histories, such as utility payments or rent, companies can identify creditworthy individuals among the unbanked or underbanked populations. This approach diversifies their customer base and opens up new revenue streams by offering financial products to a larger, yet previously deemed risky, demographic.

Integrating alternative data into credit scoring models provides a more nuanced understanding of an applicant's financial behavior, leading to more accurate risk assessments. For instance, analyzing transaction histories, savings patterns, and even social media behavior could unveil insights into a person's financial stability and reliability. This enriched data pool allows for finer differentiation between high and low-risk clients, potentially reducing default rates and enhancing the overall quality of loan and insurance portfolios.

Implementing AI-driven credit scoring models streamlines the credit assessment process, making it faster and more cost-effective. Traditional methods involve manual checks and lengthy paperwork, but AI can quickly analyze vast amounts of alternative data, delivering instant credit decisions. These alternative scoring approaches reduce operational costs by minimizing the need for extensive human intervention and accelerating time to market for financial products.

SCENARIOS

SCENARIO YEAR 2030

What if AI Redefined Financial Compliance?

In 2030, AI and machine learning have transformed regulatory compliance in the financial sector. This shift began as financial institutions and regulators recognized the potential of AI to enhance the efficiency and accuracy of compliance processes. Large banks quickly adopted AI to monitor transactions and identify regulatory issues in real-time, significantly reducing compliance costs and improving risk management.

However, this rapid adoption highlighted a growing divide. Smaller financial institutions struggled with the high costs of integrating sophisticated AI systems, placing them at a competitive disadvantage and raising concerns about a two-tiered financial system. By 2030, efforts to address this divide were underway but remained in the early stages. Initiatives included providing subsidies and developing open-source AI tools to help smaller firms afford and implement AI compliance technologies.

Regulators also began adapting their expectations, recognizing the resource gap between large and small institutions. These measures aimed to level the playing field, ensuring that all financial institutions, regardless of size, could benefit from AI in compliance.

Despite these efforts, the digital divide in financial compliance is only starting to be bridged. The industry and regulators continue to seek solutions that ensure equitable access to AI technologies, underscoring the need for ongoing innovation and policy adjustments. The journey towards a fully inclusive digital compliance ecosystem is just beginning, with the hope that further advancements and collaborative efforts will eventually resolve the disparities.

DEFI MODELS

1ST YEAR ON THE LIST

ROUTES TO WEB3

WHAT IT IS

Over the past year, despite down crypto markets, developers & institutions have made strides in integrating traditional finance & Web3. Headline-grabbing Bitcoin & Ether ETF filings have overshadowed equally impactful technical work enabling connectivity between TradFi & crypto

HOW IT WORKS

Visa is expanding stablecoin settlement by incorporating the Solana blockchain alongside Ethereum and collaborating with Worldpay and Nuvei. This move enhances the speed and efficiency of cross-border settlements, facilitating faster transactions using stablecoins like USDC. Previously, settling cross-border purchases on Crypto.com Visa cards involved lengthy currency conversion processes and expensive wire transfers.

Microsoft is partnering with Aptos Labs to bring AI and Web3 together, allowing Microsoft's AI models to train on Aptos' verified blockchain data. This collaboration aims to increase trust and transparency in AI through blockchain's immutability and verification capabilities.

For the first time, TransUnion partnered with Spring Labs and Quadrata to deliver off-chain credit scoring to DeFi and Web3 applications. This partnership will enable decentralized lending platforms to assess risk better when lending to consumers, allowing more consumers to access these platforms.

JPMorgan executed its first DeFi trade on a public blockchain, facilitated by the Monetary Authority of Singapore's Project Guardian, exploring DeFi applications in wholesale markets. Meanwhile, the London Stock Exchange Group is building the first major blockchain-powered marketplace for traditional financial assets. The platform will streamline global trading and improve speed, cost-efficiency, transparency, and security by using tokenization to represent assets like stocks and bonds as digital tokens.

WHY IT MATTERS

Traditional financial service providers risk being sidelined as Web3 technologies enable direct peer-to-peer transactions without the need for intermediaries like banks or payment processors. Web3 could erode their revenue streams and necessitate a shift in business models towards value-added services that leverage blockchain technology.

The decentralized nature of Web3 platforms complicates regulatory compliance for traditional financial service providers and insurance companies. Ensuring adherence to existing regulations while navigating new and evolving regulatory frameworks presents a significant challenge. Firms must invest in robust compliance mechanisms and engage proactively with regulators to mitigate regulatory risks.

Similarly, adopting smart contracts and decentralized protocols in Web3 presents an opportunity for traditional financial institutions to streamline operations and reduce costs. These firms can enhance efficiency and remain competitive in a rapidly evolving landscape by automating insurance claims, underwriting, and settlement processes.

Ultimately, to stay relevant in the era of Web3, traditional financial institutions must embrace innovation and invest in research and development of blockchain-based solutions. Investment may involve partnering with or acquiring fintech startups specializing in decentralized finance (DeFi) or developing in-house expertise to build and integrate Web3 technologies into their offerings.

5TH YEAR ON THE LIST

PROGRAMMABLE MONEY

WHAT IT IS

Programmable money, or "Purpose Bound Money" (PBM), refers to digital currencies or assets that can be controlled and manipulated through code or programmable logic. Unlike traditional forms of money, programmable money enables developers to embed rules and conditions into transactions, allowing for automation and customization of financial processes.

HOW IT WORKS

In late 2023, the Singapore Fintech Festival partnered with Amazon to experiment with programmable money. They provided attendees with a voucher that was placed in their digital wallet and could be spent with specific vendors; the funds were only released once the participant received the items.

JPMorgan introduced a programmable payment feature targeting institutional clients on its JPM Coin blockchain platform. This feature facilitates real-time, programmable treasury and digital business models. In November 2023, the feature went live with Siemens AG being the first to use it; FedEx and Cargill are expected to follow. The feature allows for dynamic funding and event-based payouts. JPMorgan is also said to be developing another blockchain-based solution for cross-border transactions, awaiting regulatory approval.

Pave Bank has launched with a digital banking license from the country of Georgia and $5.2 million in seed funding, led by 468 Capital and others. Pioneering as the world's first "programmable bank," it aims to transform banking by offering robust services like multi-currency accounts, global payments, and an institutional asset network, promising the safety of client funds. Highlighting the ability to bridge digital and real-world assets, it champions a significant shift in approach to combined banking services.

WHY IT MATTERS

Programmable money could streamline the operations of financial institutions and insurance companies. Currently, many aspects of companies' accounting, payables, and other financial processes are conditional and dependent upon meeting specific requirements. If programmable money does scale, it could enable firms, especially those in the finance industry, to automate a meaningful portion of their back-office operations and reduce human interaction in those tasks to oversight and validation.

While today's banking systems are still somewhat beholden to data entry, which can fall victim to human error, programmable money depends on an immutable set of criteria that can be measured and validated. As a result, the scaling of programmable money could significantly reduce errors that result from misentry or incomplete information. For the same reason, programmable money could improve transparency in financial reporting for both businesses and financial institutions.

The principles of programmable money could extend to other digitized assets, such as paperwork, contracts, or ownership certificates. In this example, the transfer of contracts or ownership could be programmed as dependent upon another factor. For example, the transfer of a digitized home deed would not be sent until the lender had received the loan proceeds. In addition to speeding up administrative processes, this new feature could help augment existing legal procedures and create a digital trail for complex transactions.

1ST YEAR ON THE LIST

ASSET TOKENIZATION

WHAT IT IS

Digitization of assets refers to converting physical or non-digital assets into digital form. This transformation allows assets, such as art, real estate, or intellectual property, to be tokenized on blockchain platforms, creating digital tokens representing ownership or a share of the asset and allowing it to be monetized in new ways.

HOW IT WORKS

One patent recently filed outlines a technology platform that leverages blockchain and AI to tokenize large-scale and traditionally illiquid assets through a novel two-tier process. It introduces General Asset Tokens (GATs) and Specific Asset Tokens (SATs), where GATs represent shared ownership in a diversified asset pool, and SATs offer individual ownership in specific assets chosen from this pool. The process is underpinned by smart contracts, ensuring secure, efficient transactions and immutable records on a blockchain network.

Salesforce recently filed a patent application that describes a system for managing assets on the blockchain through a process called Multiple Decentralized Tokenization with Personal Control (MDTPC). These tokens can be treated similarly to securities, so their trade may be subject to securities laws. Traditional blockchain asset management suffers from a lack of cross-ledger recognition and individual control over asset management. Salesforce's proposed solution overcomes these issues by allowing users to choose how and when assets are evaluated and which blockchains to use for managing their asset data.

Another invention from Data Vault Holdings describes tokenizing precious assets like real estate or art to represent ownership and facilitate transactions. A data platform receives the corporate data, which is then segmented and tokenized. The corporate data is valued, and potential monetization strategies are determined. This approach creates a way to value and exchange real-world assets on digital platforms more easily.

WHY IT MATTERS

Tokenization divides traditional assets into smaller shares, making it easier for investors to buy and sell parts of assets. This increased divisibility improves the liquidity of assets like real estate or art, broadening access to investment opportunities and allowing a wider range of investors to participate in markets previously accessible only to wealthy or institutional investors.

To achieve interoperability, institutions will need access to a comprehensive registry service that details tokenized assets in a standardized way across multiple blockchains. This visibility is crucial in establishing trust in digital transactions and verifying ownership without the need for centralized authorities.

Tokenization can reduce costs and complexity. By digitizing assets, traditional intermediaries such as brokers, banks, and lawyers may become less necessary, lowering transaction fees and disrupting the industry. Blockchain's built-in efficiency can streamline operations, reduce paperwork, and make the entire investment process more efficient.

The transparency of blockchain ensures that every transaction and ownership change is recorded on a ledger that is immutable and accessible to all participants. This level of openness enhances trust among stakeholders and facilitates compliance with regulatory requirements through programmable tokens that automatically enforce rules and restrictions related to investor qualification, geographic limitations, and trading volumes.

SCENARIOS

SCENARIO YEAR 2035

What if DeFi Reinvented Protection for High-Value Assets?

Historically, insuring high-value assets involved complex layered coverage with multiple carriers providing primary, secondary, and excess policies. This patchwork approach was necessary to cover the full extent of risk but created gaps, overlaps, and administrative headaches.

The advent of blockchain-based fractional asset ownership and programmable money has turbocharged the reinvention of layered coverage models. In 2035, when securing protection for a $50 million Cézanne painting, for example, the owner can now tokenize and sell off 15% shares to help fund a personalized smart policy administered by a single decentralized platform.

This primary parametric coverage is directly priced and programmed according to the asset's attributes. Orchestration smart contracts then dynamically spread secondary risk protection across a fluid syndicate of global capacity providers. Coverage limits, exclusions, and collateral requirements are automatically optimized, with premiums held in escrow via programmable stablecoins.

If a loss occurs, validated payouts are instantly triggered to the token holder's wallet up to policy limits. Parametric triggers and predetermined payout schedules eliminate adjusters. Excess coverage above primary policy limits is also pre-bound using prediction markets for capacity bidding.

Fractional tokenization creates the fractionalization of risk - and the ability to program predefined coverage conditional on tokenized collateral unlocks exponential configuration possibilities. Owners now bypass the friction of layered policies to achieve customized, end-to-end intelligent protection for their prized possessions.

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Melanie Subin is Managing Director of Future Today Institute, where she serves on our management committee and leads our consulting division.

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SPORTS

Future Today Institute

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TOP HEADLINES

The world of sports is being transformed by increased use of analytics, innovative platforms, and more customizable fan experiences.

01   **Analytics Get integrated Into Sports**

Sports are benefiting from data's abundance in all aspects of life, impacting both player performance and organizational management.

02   **Athletes Steal the Spotlight**

Since the days of Michael Jordan, athletes have been their own brands, but never more than now. Athletes are transcending their sports and all for the better.

03   **Personalized Fan Experiences Rise**

Personalization is now crucial for attracting and keeping new fans, and technology is enabling it across game viewing, shopping, and even advertising.

04   **Extended Reality Goes Mainstream**

XR and other augmented realities are becoming more pervasive for both live events and at-home experiences.

05   **Sports and Politics Mix**

Sports and politics have always been inextricably connected, but now, this connection is extending to the geopolitical realm.

STATE OF PLAY

A suite of technologies is creating competitive advantages for managers, coaches, and athletes, while also impacting how fans experience the game.

Technology is leaving an indelible mark on the world of sports at all levels. It is impacting how managements run their organizations and scout players, how athletes train, rehabilitate, and interact with the game itself, and how fans experience events at home and in person. While these areas seem somewhat independent of one another, they actually work in concert to affect the overall product on the field that is delivered to fans.

When it comes to managing the game, leadership and coaches are equipped with tools to make their jobs easier and remove biases. Platforms such as Plaier and AiScout are not replacing the role of the coach but are serving as supplementary tools to capture analytics and statistics that otherwise might have gone unnoticed. Such information is being stored in central repositories, such as the Chicago Blackhawks' Madhouse to inform all internal operations.

As athletes use technology to improve their skill set, they will see increased performance from a host of new innovations. Mixed reality goggles assist swimmers as they train. Virtual reality is increasingly helping athletes with reaction time and training for in-game scenarios, ultimately leading Germany's U17 football team to a championship. Platforms such as the Catapult athlete-monitoring system provide athletes with recommendations to improve performance and minimize injuries. These technologies are also impacting management and coaches' decisions.

Aside from these aspects, technology provides unique and customized experiences for fans, whether that be the game experience or how they shop and consume ancillary products. Augmented reality is providing fans with immersive experiences ranging from "Toy Story"–themed games to smart stadiums to virtual arcades. Universal golden records follow fans through omnichannel user journeys, allowing teams to engage the fans at all levels. As management teams find new ways to interact with fans, increased revenues will ultimately be used to enhance the product on the field, not just the experience in the stands.

KEY EVENTS

FEBRUARY 24, 2023

MLB Institutes the Pitch Clock
In a radical move to reduce game duration and minimize downtime, the MLB puts a time limit on pitchers and batters at the plate.

APRIL 17, 2023

Debut of the Cavs ARcade
During the NBA playoffs, the Cleveland Cavaliers use the augmented reality of ARound to create digital experiences at their Rocket Mortgage FieldHouse.

JUNE 6, 2023

PGA and LIV Shock the World
The former rivals announce their agreement to form a unified commercial entity.

OCTOBER 1, 2023

ESPN Hosts "Toy Story" Football
An animated telecast of the Jaguars-Falcons London game places NFL players in Andy's toy-filled room.

MARCH 14, 2023

Bally Goes Bankrupt
Diamond Sports, owner of Bally Sports, files for bankruptcy after missing a $140 million interest payment.

APRIL 21, 2023

Russian Athletes at ALBA Games
Russian athletes were invited to compete under their nation's flag at the 2023 ALBA Games in Venezuela.

SEPTEMBER 20, 2023

MLB Hosts Virtual Game
After launching in the summer, the MLB's virtual ballpark hosts its first regular season game, between the Tampa Bay Rays and the Los Angeles Angels.

LIKELY NEAR TERM DEVELOPMENTS

SPORTS: COMPLEX AND DYNAMIC

The sports industry is poised for a major transformation in 2024, with a host of exciting challenges and innovations on the horizon that will have a profound impact on the way fans engage with sports, creating bespoke and immersive experiences like never before. However, alongside these technological advancements lie a range of business and political obstacles that must be overcome, putting the efficiency of decision-making mechanisms to the test.

More Immersive Experiences

Sports teams already use mobile devices to provide augmented experiences and activations for in-person events, and now this capability will occur in homes. Spatial computing allows for more 3Dt renderings of a game as if you were there.

Broadcasting Rights Lead to Turmoil

As live sports broadcasting contracts become more expensive, streaming platforms and tech companies will make more competitive bids to expand their user base. However, overpaying for negotiating rights could lead to long-term financial impacts, putting streaming platforms in significant financial trouble.

Olympics Serve as a Protest Platform

The Olympics have always served as a geopolitical platform, but the 2024 Games could be exploited in unprecedented ways. Considering the Israel-Hamas war and Jewish populations in France, along with Ukrainian's aversion for Russia, the Olympics will likely serve as a venue of protest unlike what we've witnessed in the past.

Increased Web3 Adoption

This year will reveal the true usefulness of Web3 technologies such as using blockchain for creating consolidated golden records, digital fan passports, and dynamic ticketing, and highlight how these novel approaches will impact the fan experience. As teams and leagues work out the issues and take advantage of Web3, more organizations are likely to adopt it.

Influence Expands from the Middle East

Golf has felt the impact of Saudi Arabia's sovereign wealth fund through the merger of the PGA Tour and LIV. Likewise, Qatar has leveraged its sovereign wealth fund to impact soccer clubs FC Barcelona and Paris Saint-Germain. These nations will expand their control with increased economic investment in sports including soccer, boxing, cricket, and even basketball.

Automated Game Management Expands

Technologies for managing games and matches, such as electronic line calling in tennis, automatic balls and strikes systems in baseball, and semiautomated offside technology for soccer, are creating fairness and minimizing human error. More leagues will be pressured to adopt similar technologies, especially as the stakes increase from sports betting.

11 MACRO SOURCES OF DISRUPTION
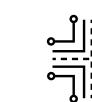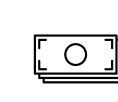
| Technology | Media & Telecom | Demographics | Environment | Government | Public Health | Education | Geopolitics | Infrastructure | Economy | Wealth Distribution |

WHY SPORTS TRENDS MATTER TO YOUR ORGANIZATION

Appropriating Environmental Solutions

Like many industries, sports play the role of both the victim and villain in climate change. The proactiveness of some sports organizations can provide lessons and solutions for smaller and more fledgling leagues or associations and for divergent industries such as the built environment.

Building a Personal Brand

Athletes are growing their individual platforms in unprecedented ways. New regulations in conjunction with a suite of technologies are offering athletes new sponsorship and monetization opportunities. These trends can impact younger athletes or even individuals in other industries hoping to grow their platforms.

Experimental Partnerships

Sports partnerships have traditionally been formulaic in nature. But now, more creative and unique partnerships are emerging. Some have matched brands with common synergies and core competencies, resulting in genuinely customer-focused services. These examples can serve as a template for other businesses seeking fresh ideas.

Customized, Personalized Advertisements

Sports associations have developed technology capable of creating targeted advertising that is customized to the market or even to individuals viewing a game. Implementing these methods, as well as frequency capping and frequency control, can result in unique advertisements less likely to disillusion the audience.

Inclusive Management Practices

While discriminatory practices in sports can occur at all levels and stages, some leagues have taken significant strides to eradicate them and create inclusive environments for employees and personnel. Other organizations, both within and beyond sports, also have valuable examples of ways inclusion has impacted their businesses.

Taking Advantage of Virtual Environments

The sports industry has embraced virtual environments and virtual reality as tools for training and conditioning. Although VR cannot fully replace real-life experience, it has shown to have a positive impact on athlete training. Other industries can learn from these examples and add new training modalities to their arsenal.

OPPORTUNITIES & THREATS

Threats

Legacy sports organizations must attract younger audiences to avoid financial losses. The MLB has taken steps to address this issue, but it remains to be seen whether they are enough to guarantee long-term success.

The speed of sports is getting faster, and with that comes the increased risk of injury to athletes. Organizations not exploring regimens to ensure reduced injuries are setting themselves up for failure, and ultimately an impact on revenues.

As climate change worsens, sporting events, especially those conducted outside, could become less tenable. Even indoor sports such as hockey could be impacted by rising global temperatures.

Using technology to address inclusivity and accessibility can prove to be valuable, but not fully pressure testing the technology can result in failure if it makes target audiences feel even more marginalized.

It is becoming more common for sports organizations to use centralized management tools or create a centralized operating system. Organizations that do not use these tools risk falling behind their competitors.

Opportunities

There is an immediate opportunity to resolve issues plaguing distribution models. The organization best poised to navigate regulatory hurdles and engineer new digital platforms could disrupt the market.

Individual sports teams will find tremendous benefits from building golden fan records and digital sports passports. Such platforms will enable teams to fully know their customers and track them through the entire customer journey.

Customized and personalized experiences and activations are becoming more viable and executable. They can be used to engage fans in ways that leave them feeling surprised and delighted.

Hosting destination sporting events in picturesque locations can be costly and difficult to carry out. However, new technology is enabling sporting events to take place in any virtual environment, offering fans special experiences.

Advanced analytics and artificial intelligence are leaving a lasting mark on various aspects of sports, including player performance, scouting, and team management. More opportunities will surface for using such applications in the future.

INVESTMENTS AND ACTIONS TO CONSIDER

1

Investments in sports science have dual benefits. Fewer injuries or reduced time lost to injuries is immeasurably beneficial to both sports teams and athletes. But value also comes from these new procedures becoming increasingly available to the general public.

2

Creating immersive experiences in extended reality will keep fans engaged, whether they are at a sporting event or watching from home. Mastering these new forms of storytelling can give organizations new revenue-generating opportunities if they share their knowledge through consultation with other groups.

3

Sports organizations will increasingly chase sustainability, whether that comes from an intrinsic need to help the environment or from a desire to impact their bottom line. First movers in this area will initially benefit from the advantage of sustainable practices, but can also sell climate IP to other businesses.

4

Seek out partnerships with organizations adjacent to your own but not entirely in your domain. One example of such a partnership is that of the WWE and UFC: Together, these brands can cater to both audiences without cannibalizing their business. It also avoids antitrust violations.

5

Invest in technology and platforms aimed at building individual brands for athletes that help expand their reach and audience size. The phenomenon of athletes as brands is only becoming more pronounced, and organizations that can help facilitate this growth will reap significant benefits and rewards.

6

While risky in nature, upstart leagues offer opportunities, though they'll require unique value propositions. While examples like Tiger Woods' and Rory McIlroy's experimental golf league benefit from celebrity backing, there are significant investment dollars to be earned for such endeavors.

CENTRAL THEMES

Reach Fans Wherever They Are

The way we consume sports is ripe for change—and innovative solutions. Over the past year, it's become obvious that archaic distribution models are no longer adequate. Diamond Sports' Chapter 11 filing indicates that as consumers move to leave cable television in droves, the traditional way of broadcasting games is no longer a sustainable way to reach fans, and in turn a poor generator of revenue. Fans who have moved away from cable often cannot access local games because of blackouts. Even subscribers of streaming options like YouTube TV, Hulu + Live TV, or Sling TV have been prevented from watching their games of choice because of issues with renewal agreements. In response, Phoenix Suns owner Mat Ishbia has turned to primitive methods to reach fans, by offering free antennas that can access local broadcasting games. Such solutions will continue to be needed until new models of consumption are available to the masses.

Expanding to Younger Audiences

Reaching newer fans and younger demographics is challenging, and so is keeping their attention for prolonged periods. Gen Zers consume sports much like they consume other media, producing headwinds for the industry. According to Morning Consult, 54% of Gen Zers spend at least four hours daily on social media, primarily on YouTube, Instagram, TikTok, and Snapchat. These are also the very platforms where most Gen Zers discover news related to sports. Short-form media is obviously limiting when it comes to attracting this audience to full-length sporting events, but sports executives realize the magnitude of the challenge. To grow interest among even younger audiences, such as Gen Alpha, networks can continue to broadcast fully animated sporting events through partnerships with brands such as Disney's "Big City Greens" and "Toy Story."

Sports Tech's Alternative Uses

The most cynical among us may question the utility or meaning of sports, pondering why professional athletes are paid such exorbitant salaries to essentially play a game. But sports can justify itself to even the harshest critics through the innovations it brings to adjacent and seemingly unrelated industries. The sustainability measures implemented in auto racing and new stadium operations can be carried over to how we live our everyday lives, providing new solutions to address existential climate threats. Advances in sports medicine can have tremendous impacts on human health and longevity that could one day be available to mass markets. Advances in wearable technology can improve health diagnostics for general consumers. Sports can serve as the platform to resolve our cultural, political, and social conflicts and sticking points. In this way, sports transcend mere play and competition, emerging as a dynamic force that enriches our lives and champions progress.

Vulnerability Breeds Reactivity

Sports leagues, like many legacy organizations, have often been slow to evolve. Because of the hesitancy to make large-scale overhauls, sports leagues make themselves vulnerable to outside pressures. Consequently, specific leagues have been forced to make reactive decisions to remain relevant or as a means of protecting themselves from impending competition. Major League Baseball, a league traditionally resistant to change, took on the risks of implementing the pitch clock, step-off limits, bigger bases, and PitchCom for pitchers—to mixed results. As another example, such vulnerability forced the PGA Tour to seek partnership with its biggest rival, LIV, completing a full reversal of its initial stance and completely ignoring legal conflicts in the process to foster the merger. When sports leagues are slow to adapt, they ultimately will be caught flat-footed and forced to make decisions that can be inconsistent with their core values.

ONES TO WATCH

Sandy Khaund, CEO and founder of Credenza, for his contributions to Web3 and blockchain software revolutionizing the sports experience.

Brian Kaiser, co-founder at Hudl, for developing software that provides video analysis and coaching tools for sports teams.

Aron D'Souza, president of the Enhanced Games, for controversially pushing the boundaries of athletic competitions to drive human innovation.

Mat Ishbia, owner of the Phoenix Suns, for commitment to increasing accessibility of sports for his local market.

Shawn Beaudette, assistant professor of kinesiology at Brock University, for his contributions in creating a 3D motion capture system to impact sports performance.

Michael Horvath, co-founder of Strava, for developing technology that makes exercising more engaging and interactive.

Joel Embiid, basketball player for the Philadelphia 76ers, for launching Miniature Géant, a new production studio that amplifies voices and inspires a new generation of athletes.

Jeffrey Jordan, co-founder of Heir, for serving Gen Z fans by providing community-focused content centered around their favorite players.

Alex Morgan, Sue Bird, Chloe Kim, and **Simone Manuel,** co-founders of TOGETHXR, for creating a platform to uplift the next generation of women in sports.

Chen Shachar, co-founder and CEO at PlaySight Interactive, for his contributions to the emerging market of affordable consumer sports analytics systems.

Oliver and Amber Marmol, co-founders of VS, for launching an edtech platform aimed at mentoring aspiring athletes.

George Sun, CEO and founder of Nextiles, for merging flexible electronics with soft goods to create a data analytics platform that measures human performance.

Olivia Dunne, American gymnast, for making it easier for female athletes to secure endorsement deals.

Phil Southerland, founder of Supersapiens, for using biosensor packs to create a system providing real-time glucose visibility to athletes.

Dr. Per Reinhall and **Dr. Samuel Browd,** co-founders of VICIS, for protecting players through innovative helmet designs.

Ben Sherwood and **Reed Shaffner,** co-founders of MOJO Sports, for creating a platform that keeps kids more engaged in sports.

Ted Sullivan and **Kiril Savino,** co-founders of GameChanger, for creating a tool kit to help athletes self-promote and get noticed.

Jonathan Soros and **Jon Patricof,** co-founders of Athletes Unlimited, for creating a public benefit corporation to empower elite women athletes.

Marie Donoghue, vice president of global sports video at Amazon, for bucking the trend of linear viewing and offering a new way of watching football.

Jan Wendt, Tim Schröder, and **Johnny Wilkinson,** co-founders of PLAIER, for developing a platform that democratizes player scouting in football.

Darren Peries, founder of Ai.io, for creating a platform to assist clubs and scouts in finding and developing amateur players.

Adam Silver, commissioner of the NBA, for unabashedly bringing innovations to a major sports league.

Eileen Jurczak, CEO of Xonic Golf, for creating iTQ, an AI-powered caddie app tailored to each golfer that provides real-time quick tips on how to improve.

IN THE STANDS

FAN EXPERIENCES

FLEXIBLE CONTENT MODELS

WHAT IT IS

With the rapid demise of regional sports networks (RSNs), flexible and accessible content models will need to fill this new void. Direct-to-consumer streaming services could meet fans' expectations for personalized, flexible, and high-quality experiences. New platforms are emerging to give these fans what they want.

HOW IT WORKS

Recast offers an alternative to traditional ad-based or subscription models for content consumption. Users are given the option to pay for content by either using an in-platform currency or by earning credits from watch ads. This serves as a flexible and privacy-laden solution for viewers while content creators benefit from larger shares of the revenue. Recast has currently been adopted by the World Curling Federation and the Hibernian Football Club of the Scottish Professional Football League. ESPN is exploring a one-stop shopping model that would connect fans to live sports broadcasts from various streaming services directly on its platform. ESPN would receive a portion of the revenue generated from sales, with the remainder going to streaming services originally in possession of the broadcast rights. Roku has delivered the Women's Sports Zone, a centralized hub on its platform that simplifies access to women's sports content. It aims to match the increasing demand for women's sports content and make it easier for viewers to access and watch. Google is adding new features and offerings for its YouTube TV coverage of the NFL Sunday Ticket package, including monthly payment plans, discounted options for students, features allowing viewers to watch multiple games at the same time, live chats, polls, and e-commerce integrations.

WHY IT MATTERS

RSNs in the United States are in dire circumstances, facing challenges from changing consumer habits in conjunction with other economic forces. In 2023, Diamond Sports Group, which runs the notable RSN Bally Sports, filed for Chapter 11 bankruptcy protection and missed payments to many of its partnering sports teams. Many RSNs are now exploring direct-to-consumer platforms, but existing contractual agreements are complicating such transitions. While the landscape is in flux, teams, leagues, and RSNs are scrambling to develop sustainable business models for consumers who value flexibility and accessibility.

A survey conducted by Verizon Media indicates that sports fans are largely willing to pay more for live sports streaming, but only if providers give more access to the sports teams and leagues they are interested in. The research ultimately determined that fans are demanding more personalized, flexible, and high-quality sports streaming experiences. In order to meet fans where they are, tremendous collaboration is required from forward-thinking sports leagues and media partners, as well as the patience needed to navigate the murky landscape of content distribution contracts. Regardless, the current distribution system is no longer sustainable, but the landscape is ripe for new opportunities.

FANDOM ON THE BLOCKCHAIN

WHAT IT IS

Sports teams are increasingly using blockchain and other Web3 technologies to enhance fan experiences by creating a consolidated golden record, digital passports, or enhanced ticketing experiences. Teams will now be able to keep a universal record across multiple channels and track fans' interests and preferences through their entire user experience.

HOW IT WORKS

The St. Louis Blues, a professional hockey team, have a multiyear agreement with Credenza Inc. to integrate Web3 software and technology into their preexisting fan engagement platform, Bluenatics. This new platform iteration called Bluenatics Passport will effectively function as a universal ID, by tracking fan activities across ticketing, online purchases, concessions, in-person retail, and partner locations, and keeping a centralized repository of fan experiences across multiple touchpoints. Similarly, with their move from Oakland to Las Vegas, the Raiders needed to better understand their new customer base. The football team consulted Data Clymer to create their own golden fan record using Salesforce for customer data, Matillion for data extraction and transformation, Snowflake for data storage, and Tableau for analysis and insights. Sports Illustrated Tickets will use Web3 architecture for a different purpose: Its Box Office, a blockchain-based ticketing and event management platform, will offer the Super Ticket NFT product, which links video highlights, exclusive offers, and loyalty benefits to a ticket, enhancing customer relationships and providing greater visibility in resales. The project involves collaboration with ConsenSys and Polygon. By using their platforms and technology, Box Office will offer a more flexible, scalable, and cost-effective way of managing inventory and customer interactions.

WHY IT MATTERS

Web3 software has the power to revolutionize fan experiences and interactions. By having a consolidated record across multiple channels of a fan's habits, purchases, and behaviors, teams and brands can offer fans real-time discounts, offers, and exclusive experiences. Teams will have the opportunity to offer fans rewarding gamified experiences tailored specifically to the individual. They can enhance customer interactions through surprise-and-delight experiences, including free or discounted tickets, merchandise, or gift cards. Teams and brands can work directly with sponsors to craft unique activations touching on preferences and habits, backed by user data and analytics.

By having a comprehensive knowledge of each fan's habits and behaviors, teams will be better equipped to craft personalized marketing campaigns, delivering customized messages and offers as they form stronger relationships and boost engagement. Through unified records and omni-channel strategies, teams can curate experiences for fans at every possible touchpoint.

Through other applications of Web3 technologies, brands can tie personalized video highlights and other engaging and collectible content to the digital ticket or customer record. Fans will be empowered by having more visibility into ticket reselling, sharing, and gifting. Web3 technologies have the ability to imbue new life and opportunities into traditional ticketing experiences.

ADAPTIVE, DYNAMIC, AND IMMERSIVE ADVERTISEMENTS

WHAT IT IS

Perhaps to the disappointment of fans, advertising through multiple channels has become more advanced, pervasive, adaptive, and dynamic. Advertising can be adapted during live broadcasts to cater to specific geographic audience segments or remain consistent across physical and digital realms.

HOW IT WORKS

The German professional football league Bundesliga was the first major European football league to adopt virtual advertising technology for broadcasted games. This technology digitally inserts advertising imagery onto LED perimeter boards surrounding the pitch and dynamically changes during the course of the match. This advertising is not viewable to the players or the fans in the stadium, only those watching from home. However, ads are different and tailored to specific regions. During the 2022-2023 season, the National Hockey League became the next major league to adopt similar technology. For these digital ads, the NHL partnered with the virtual ad company Supponor, and the initiative took seven years to develop.

Conversely, the Washington Commanders are using Bidstack Sports' virtual advertising technology to create consistency across different channels. Bidstack's technology actually synchronizes and manages activations both at the team's physical stadium and in digital environments like video games and the metaverse.

Millions.co is trying to capitalize on the hype of generative AI by developing an automated athlete influencer campaign tool. Brands can turn plain English statements into AI-developed campaigns that feature multiple versions. Brands can further customize content using specifics such as location, demographics, budget, and type. The AI purportedly then optimizes the strategy based on these inputs.

WHY IT MATTERS

As long as sports remain a major source of entertainment, companies will continue to develop new methods of advertising to reap the revenue that comes with it. After disruptions due to the COVID-19 pandemic, the NHL explored advertising opportunities to make up for lost revenues. The integration of dynamic board advertisement was undoubtedly to the benefit of the league; however, this did not come without criticism. Early on, fans complained that moving ads were distracting, and on several occasions, the glitchy software has resulted in obstructed views of the game. The technology has also been criticized for being problematic for those with sensory processing issues; however, the digital ads were nominated for a Sports Emmy Award, revealing their value for sponsors and owners.

To optimize the fan experience in the face of advertising, brands can adopt specific techniques. By including frequency capping and frequency control, viewers will not see the same advertisement repeatedly, reducing fatigue and annoyance, and enhancing fan engagement. Contradictorily, when teams such as the Washington Commanders create consistency of advertising across physical and digital realms, fans can have an elevated experience when playing video games, feeling more closely connected to the real modality. This also creates expanded revenue opportunities for teams and organizations.

IN-PERSON MIXED REALITY EXPERIENCES

WHAT IT IS

Mixed reality, or the merging of real-world environments with computer-generated elements, is upgrading in-person fan experiences at sporting events. Through MR integrations, teams have new ways to engage with fans and fans have more dynamic experiences.

HOW IT WORKS

In 2022, the Minnesota Twins were the first major sports team to bring augmented reality to their home stadium. ARound, an AR app developed by Stagwell, allows fans to use their smartphones during breaks in the baseball game to play interactive games with other fans at Target Field. The app uniquely creates shared AR experiences for multiple fans. The Los Angeles Rams also hired Stagwell to create an AR experience for football games using ARound. The application features AR effects, interactive content that coordinates with touchdowns and other events, unique player animations, and other in-game prizes and contests. German football league Bundesliga has collaborated with TV broadcaster Sky Deutchland and mobile operator Vodafone to create similar augmented applications on phones that offer multiple camera views and instant replays as well as graphic overlays with statistical information and analytics directly on the pitch. Through a different approach, the International Basketball Federation has installed LED glass courts to augment the fan experience. Real-time statistics and other graphics that directly appear on the court increase fans' understanding of the game and the action in front of them—and encourages them to look up, away from their smartphone. The NBA has also begun experimenting with the floor, leveraging it for part of the 2024 All-Star weekend. The celebrity game, skills competitions, and famous dunk contest all took advantage of the augmented court's abilities. However, the All-Star Game still occurred on a traditional wooden court.

WHY IT MATTERS

AR experiences provide sports teams and brands with new revenue streams and sponsorship opportunities. These can be offered not only at stadiums but also to those streaming or viewing live sporting events from home. More importantly, these experiences can cater to younger audiences—especially valuable for leagues such as MLB facing the challenge of reaching and retaining younger generations of fans. Potential sponsorship opportunities include branded AR filters, virtual billboards, or advertising space.

AR also brings value propositions for the fans. Through such technology, they can have access to real-time advanced stats with accompanying visual overlays to help them better understand an individual player's performance compared to the competition. Historical data visualizations enhance the experience, providing context and comparison to past performances. Interactive data experiences can provide fans with unique and immersive ways of engaging with the game. Finally, AR applications can also serve as an educational tool for fledgling fans trying to learn more about the sport.

1ST YEAR ON THE LIST

AUGMENTED EXPERIENCES AT HOME

WHAT IT IS

When it comes to broadcasted or streamed sporting events, the US' four major sports leagues are using innovative digital and virtual experiences to cater to new fans both young and old. These experiences can place your favorite sport in your favorite virtual setting, or they can place a virtual representation of you directly in the game.

HOW IT WORKS

Earlier this year, Super Bowl LVIII featured a special kid-centric broadcast on Nickelodeon, marking the first time the Super Bowl has had a separate telecast on another network. For the production, Nickelodeon's visual style was incorporated, including slime-filled end zones and appearances by characters like SpongeBob SquarePants. In a similar vein, ESPN, Disney, and the National Hockey League collaborated to create the NHL Big City Greens Classic. This innovative broadcast, made possible through player and puck tracking data, re-created an entire hockey game in real time within a virtual environment, using animated players whose movements and actions were synchronized with the athletes on the ice. During the 2023 NBA All-Star Tech Summit, Commissioner Adam Silver demonstrated a future live game streaming experience where fans can scan their own avatar and place it in the game to replace an actual player. MLB has debuted a new virtual ballpark currently accessible only on the web that allows fans to make customizable avatars with their favorite MLB jerseys and offers opportunities to interact with other fans virtually and participate in various mini-games. The virtual ballpark resembles an actual baseball stadium and features stands occupied by virtual spectators. A giant screen within the park livestreams games and other content.

WHY IT MATTERS

Augmenting the at-home sports viewing experience is another of the industry's attempts to attract and cater to younger audiences and generations. According to Morning Consult, almost three out of five members of Gen Z who have not watched a sporting event on TV in the past few years said the major reason was a lack of interest in sports. Following that, 20% claimed games were too long. Reflecting the shorter attention spans that viewers have developed in our digital age, Gen Zers primarily get their news about sports from YouTube, Instagram, and TikTok but don't use these applications to livestream full games. As a result, sports teams and leagues are increasingly focused on the "game beyond the game" as a way to attract younger consumers. As the NFL attempts to do this with its Nickelodeon partnerships, such broadcasts can serve both younger and older audiences, as added graphics do not completely obscure the game and invested parents can still enjoy a semblance of a football game. The NHL's approach with the "Big City Greens" collaboration will primarily just serve a younger audience, but the virtual environment could do more to keep them captive. However, either approach could be seen as too gimmicky and disillusion traditional fan bases. Still, customization is now the name of the game, and these virtual experiences deliver just that. Through such channels, fans can have a wider selection of alternate languages, high-profile influencer and celebrity commentary, enhanced camera angles, and even integrated betting.

SPORTS BETTING AND INVESTING SOARS

WHAT IT IS

Technology and evolving regulations have changed the way that individuals place bets and make sports investments. The ease of access to new data, options for live betting, and mobile applications are bringing these services to broader audiences eager to win a large payout.

HOW IT WORKS

The combination of new technology and accessibility through mobile devices has caused the sports betting and investing industry to grow exponentially in the past several years. Seeing this value, in 2023, American licensed sports-wear retailer Fanatics acquired the US operations of Points-Bet, the sports wagering operator and iGaming provider that offered scalable cloud-based technology platforms. This move marks Fanatics' entry into sports betting, giving it access to 15 states where PointsBet was licensed to operate.

To benefit the bettors and fledgling investors of sports, a host of technologies are being developed to enhance the customer experience. The sports investment app Common-wealth is revolutionizing horse racing ownership by letting individuals buy shares in racehorses for as little as $50 and earn a portion of the horse's winnings. Rithmm is a sports betting application using predictive analytics to inform bettors' decisions and ultimately enhance their performance. The app allows users to build a custom analytical model backed by AI and based on their instincts, providing analysis for every game, recommended picks, predicted scores, win probabilities, and expected value on market odds. Rithmm aims to make users more informed and thereby make sports betting more accessible.

WHY IT MATTERS

Over $180 billion has been legally wagered on sports in the past five years, generating $13.7 billion in revenue for sportsbooks. In 2022 alone, American consumers allocated a larger portion of their spending to sports betting compared to expenses for ride-sharing apps and streaming services, with a total of over $95 billion legally placed in bets within the nation. About 18% of American adults, or over 46 million people, either place bets or plan to place bets on sports during a single season. Regarding sports investing, Commonwealth enabled 390 shareholders of the Kentucky Derby winner Mage to increase their overall investment from $170,000 to $5 million by selling shares at $50 each.

Technology is making both forms of activity more accessible and more attractive to a new demographic. Both betting and investing are attracting younger males in particular, who are looking to spend their disposable income. Additionally, the ease of accessibility through mobile sports betting apps in conjunction with tech-enabled quick payouts is leading to the adoption of new forms of betting and investing. However, this new trend is not devoid of concern. While sportsbooks have seen tremendous gains over the past few years, there is the worry that even with relaxed regulations in new states, the sports betting market might already be close to hitting its ceiling. But the bigger concern is the threat of increased gambling addiction. As betting only becomes more frictionless, so does the threat of an addiction epidemic.

DESTINATION SPORTING EVENTS

WHAT IT IS

Professional sporting leagues have constructed outdoor facilities to enhance the viewers' experience, providing spectacular and picturesque environments to engage fans, both old and new. The advent of new technologies could enable sporting events to be hosted virtually in any location imaginable.

HOW IT WORKS

More than a decade ago, the National Hockey League began its annual outdoor ice hockey game, the Winter Classic, which was typically hosted at iconic football and baseball stadiums. In 2021, during the COVID-19 pandemic, the NHL televised a unique take on this concept, hosting two games without in-person fans near Lake Tahoe, instead focusing on natural landscapes capable of mimicking pond hockey. In a similar vein, Major League Baseball hosted its own events in iconic and scenic locations in 2021 and 2022. In both years, they took place at a ballpark adjacent to the "Field of Dreams" movie site in Dyersville, Iowa, a location popularized by the 1989 film. In 2023, NASCAR held the Grant Park 220 in the streets of downtown Chicago: the first time the NASCAR Cup Series held a street race. This developed from an imaginary street course NASCAR conceived of in 2021 for the eNASCAR iRacing Pro Invitational Series—a series of simulated racing events that occurred during the pandemic. And even when games wouldn't physically take place in scenic venues, technology can step in: The NHL is considering using the puck-tracking technology featured in last season's popular Big City Greens Classic to expand virtual viewing feeds in locations such as the National Mall or Central Park. This technology offers endless possibilities for projecting games in captivating locations.

WHY IT MATTERS

Organizing sporting events in nontraditional locations involves some level of risk. These spectacles are exorbitantly expensive, and low ratings could result in failure. But recent events have paid off. For instance, the Lake Tahoe NHL game featuring the Boston Bruins and Philadelphia Flyers drew over a million TV-only viewers, making it the most-watched NHL regular-season game on cable since 2002. It was also the most-streamed game in NBC Sports Digital history. Similarly, the Field of Dreams game between the Chicago White Sox and the New York Yankees attracted an average of 5.9 million viewers across TV and streaming, making it the most-viewed MLB regular-season game on Fox Sports since 2005. Additionally, this production was praised for its storytelling capabilities. Although the pandemic may have contributed to the success of these two examples, NASCAR's Grant Park 220 was also deemed a success and was the second-most watched race of the season. These events should be commended for their innovativeness, as they have the potential to encourage leagues to explore international expansion in more exotic locations and potentially grow global audiences. With new digital technology, leagues can also experiment with hosting events in virtual locations to test groundbreaking ideas before investing in expensive physical locations.

SCENARIOS

What if customizable content puts viewers in complete control?

While disappointment and frustration were the hallmarks of trying to access sports during the early 2020s, by the end of the decade, accessibility is no longer an issue because of the abundance of flexible content models. Sports fans have full access along with complete customization options. AI recommendation engines suggest content to users before they even access their personal portals. Once logged in, the system automatically selects the preferred viewing area of a particular user, whether that's directly behind the backboard or from an aerial birds-eye view. The viewer can change this with ease in real time as their preferences shift. The platform also suggests iconic overlays to virtually house the game in locations such as the Roman Colosseum or on the surface of Mars. If this isn't a viewer's thing, they can simply opt for the traditional analog setting. When the platform senses users are losing interest, it engages them in activations and activities to heighten the experience. And if you thought this could only be enjoyed at home, viewers can have the same experience in the stadium using augmented reality headsets. With all of their preferences saved, all viewers have to do is remember their headset. They can enjoy all their favorite customized settings at home or on the road.

ON THE FIELD

ATHLETE EXPERIENCES

AUGMENTED GAME MANAGEMENT

WHAT IT IS

Leagues are increasingly using technology to augment or even replace human judgment and help make rulings within sports games. Some will colloquially refer to this phenomenon as *robo umpires* or *robo officials*. As the pace of sports becomes faster, an argument could be made that technological assistance can add integrity to the games.

HOW IT WORKS

The Association of Tennis Professionals announced that Electronic Line Calling (ELC) Live will be implemented into all matches beginning in 2025. Chair umpires will still oversee matches, but ELC Live will eliminate the role of line judges. In European football, the Champions League introduced semiautomated offside technology during the 2022-2023 season in an effort to improve the accuracy and speed of offside calls. This technology uses 12 specialized tracking cameras positioned underneath the stadium roof to closely monitor the ball's movement, capturing up to 29 distinct data points for each player on the field at a frequency of 50 times per second. The 29 data points account for all pertinent limbs and extremities needed to accurately determine offside calls and allow for accurate calculations of a player's on-field positions. As of 2023, all Triple-A ballparks now use robot umpires to call balls and strikes using the Automatic Balls and Strikes system (ABS). Half of the games will use an ABS challenge system where team managers can challenge calls—which will be overturned or upheld at ABS' discretion—while the remaining games will use ABS to determine all calls using an electronic strike zone.

WHY IT MATTERS

By implementing technology assistance into sporting events, the overall hope is that it would at the very least result in consistent calls, and at best ensure accuracy and perfection in the moderating of the games. As sports betting becomes ubiquitous, an increasing number of fans will endorse such technology, especially as they have money on the line, and the difference of millimeters, undetectable to the human eye, could mean the difference in a major payday or a significant loss. But purists will be more critical of the technology, saying that it goes against the spirit of the game and even that human error is fundamental to the sport. Implementing technology assistance into more events will affect stats, records, and individual achievements of athletes moving forward. Despite the view of fans from these individual camps, there are additional benefits for implementing such technology. It does have the potential to bring about consistency in officiating. The ABS system establishing a consistent strike zone has already received overwhelming positive support. Additionally, this technology could eliminate arguments with officials and make the games fairer. However, to ensure fairness in all instances, it will be complicated and difficult to develop more technology to completely replace officiating.

VIRTUAL TRAINERS

WHAT IT IS

Virtual reality is increasingly being used for training regimens and conditioning. While not a substitute for the real thing, VR provides athletes with simulated scenarios that can enhance reaction time and decision-making, giving them new skills and perspectives to use in live game situations.

HOW IT WORKS

Sense Arena has been around since 2018, and since then has been pioneering the use of VR in training for both hockey and tennis. The comprehensive platform features over 60 drills that can be tailored to specific age groups and skill levels. Organizations including the NHL and USA Hockey have recognized the potential value of such training, which can place players in realistic game-like scenarios off the ice. The University of South Florida has recently introduced Sense Arena to its tennis program, allowing players to engage in training sessions without needing a full tennis court. To help simulate real-world experiences, players can adjust settings such as wind speed and court surface, and be subjected to crowd noise. Germany's U17 football team has also turned to virtual reality to train its players, specifically to improve their awareness, decision-making skills, scanning ability, and cognitive skills. The team cites such training as instrumental in achieving their first European U17 Championship in 14 years. Tulane University is also employing VR in its athletics program; however, it is taking a slightly different approach. The program uses VR headsets to help athletes achieve a more relaxed state before or during games and competitions. The Tulane football team has specifically used the headsets to deal with overheating, muscle cramps, and injury rehabilitation.

WHY IT MATTERS

Using virtual reality to train athletes might appear gimmicky or awkward to some. It might also be met with criticism or doubt from specific athletes themselves. While of course virtual reality is not a sufficient substitute for the real thing, it can augment and assist traditional training and is proving to have its place in robust athlete training regimens. For athletes such as hockey players, VR can enhance their decision-making skills and overall performance. It can provide intense and targeted training scenarios for players, and it can position them in real-world situations at times when ice time is not available. Also, it can offer training opportunities to athletes with reduced risk of injury, as they can train without the risk of a 100 mph slap shot going high and striking them in the face.

Virtual reality training will not be for everyone, but it is already proving to be effective. As the fidelity of virtual experiences improves, so will the capabilities it will offer in the virtual training realm, providing athletes with more ways to train, even from the comforts of their own homes.

1ST YEAR ON THE LIST

AUGMENTED TRAINING ANALYTICS

WHAT IT IS

Sports programs and teams are turning to a constellation of technologies including motion capture devices, cameras, sensors, machine learning, and AI to improve player performance and training. By establishing clearer training objectives, both coaches and individual athletes will find benefits, impacting wins and career earnings.

HOW IT WORKS

Duke University's basketball program has implemented the Catapult athlete-monitoring system, which employs advanced sports science technology to enhance player performance and development. This system makes use of sensors, accelerometers, GPS, wearable anchors, force plates, body weight tracking, and biomechanical analysis. The New York Yankees have developed a state-of-the-art pitching facility and player development complex named the Gas Station. Within the facility are Trackman (radar) portable machines, Rapsodo (radar and camera) machines, high-speed Edgertronic cameras, and other equipment that produce real-time feedback for pitchers based on elements including spin rate, spin axis, vertical and horizontal drop, and velocity. Wake Forest University also employs a pitching lab that uses advanced technology including motion capture cameras, force plates, and video software to develop in-depth analysis of pitchers' movements and mechanics. Shawn Beaudette, an assistant professor of kinesiology at Brock University, has partnered with Chalk Monkey Labs to create a 3D motion capture system to impact sports performance. The technology employs reflective markers and specialized cameras to record movement data, which is then analyzed by machine learning and AI to help coaches establish objective benchmarks to help athletes make improvements.

WHY IT MATTERS

Coaches and athletic programs will try almost anything that promises to provide a competitive advantage. As it is, coaching can also be quite subjective, and coaching suggestions can sometimes be perceived as arbitrary. But by implementing tools such as machine learning and AI into performance analysis, coaches can gain a clearer understanding of player potential and use established benchmarks to arrive at a more quantified approach to their coaching, potentially minimizing biases that can impact their athlete assessments. Such systems can better gauge player intensity during games and practices and inform coaching staff of how to best adjust workloads for players during games. Analysis from these systems can also help players reduce their risk of injuries.

These systems might recommend just minor adjustments to athletes' performance and execution, but even the most minor adjustments can have monumental effects. Through practice and time, players can make holistic behavioral changes and adjustments to their game, which is especially beneficial during early and more formative years. This could really benefit individual athletes when they are ready to sign their next contract, and could mean the difference in millions of dollars.

ATHLETES AS BRANDS

WHAT IT IS

Many athletes, like NBA legend Michael Jordan, have gone beyond their sports and created their own brands. This trend has become more prominent in the age of social media. With new technologies and regulations, a new generation of athletes can rise above their sports and create their own platforms.

HOW IT WORKS

Joel Embiid, a six-time NBA All-Star, is entering the media industry by launching a production studio called Miniature Géant in partnership with The SpringHill Co., backed by LeBron James and Maverick Carter. The studio aims to inspire and showcase stories of individuals who have achieved success through unconventional paths. Miniature Géant will explore various media formats, including unscripted, scripted, audio, and branded content. Jeffrey Jordan, Michael's son, co-founded a Web3 sports technology venture called Heir. The company has launched its first mobile app, which aims to serve Gen Z fans by providing community-focused content centered around their favorite players. Users can communicate with partner athletes, access exclusive content, and find player-focused highlights and statistics. The app also offers community features such as games and events with rewards. Current NBA stars and other athletes have already joined Heir with more expected soon. Olivia Dunne, an American artistic gymnast and social media personality, has taken advantage of a 2021 Supreme Court ruling that allows college athletes to capitalize on their names, images, and licensing (NIL). With over 4 million Instagram followers and 7.6 million TikTok followers, she is considered the top female athlete social media influencer and is estimated to be worth $3.3 million. Dunne indicated that she has received over half a million dollars for a single post, making her one of the highest-earning college athletes in the NIL era.

WHY IT MATTERS

During Michael Jordan's athletic career, he was the face of multiple brands. But he didn't own his intellectual property during the peak of his fame. Additionally, he did not have the advantage of direct social media interaction with fans. Present-day athletes have more opportunities to benefit from technologies and platforms. With the emergence of social media, athletes have become media companies themselves. They can produce and distribute content directly to their fan base, shaping their brand and monetizing their influence. This shift allows athletes to control their narratives and tap into new revenue streams through endorsements and content licensing. By generating unique content such as podcasts, documentaries, web series, or books, athletes can diversify their revenue streams and strengthen their brand equity. Owning this IP gives them greater control over their content and the ability to license it to various platforms to generate income. With recent changes to NIL regulations, athletes can benefit from their personal platforms earlier in their careers. By embracing a media company mindset, utilizing social media, and focusing on original content creation, athletes can experience significant financial growth and open doors to new opportunities. This approach empowers athletes to control their narratives, expand their reach, and build strong relationships with fans and partners.

1ST YEAR ON THE LIST

INNOVATIONS IN EQUIPMENT

WHAT IT IS

Sports equipment is technology in and of itself, enabling athletes to achieve new feats and break previous records. Innovations in equipment have led to enhanced experiences for sporting events by improving player performance, making sports more entertaining, and reducing injuries.

HOW IT WORKS

The sports equipment manufacturer Wilson has developed a prototype for a 3D-printed airless basketball that never requires inflation. Wilson collaborated with EOS, an additive manufacturing company to create the lattice-based structure made from elastomeric polymer. The prototype primarily protects against deflation issues and contraction that can be caused by temperature changes. Per Reinhall and Samuel Browd worked together to start VICIS, a helmet company that makes soft-shell helmets designed to more efficiently absorb impacts. VICIS has worked with the NFL to manufacture position-specific helmets, customized for protection for key situations different football players find themselves in. Using a deformable outer shell, these helmets have contributed to reducing head injuries in football. MLB pitchers are now allowed to use PitchCom devices during games. These wearable transmitters allow players to communicate with one another on the field without giving away visible signs or verbal cues. Players (primarily pitchers and catchers) can use the device to send audio signals to other players indicating the desired pitch to use on a batter. This helps eliminate sign-stealing by opponents and offers language versatility to players whose native tongue is not English. BetterGuards braces are transforming basketball by offering players unprecedented 360-degree freedom of movement, while also providing paramount ankle protection.

WHY IT MATTERS

Innovations to sports equipment can impact the game at large, or just offer individual players customization and personalization. As the industry makes changes and advancements, not all innovations will be well received, but efforts to improve sports through experimentation are still applaudable behaviors.

Ultimately, innovations to athletic equipment can improve the pace of play, make sports more entertaining, reduce injuries, or even impact sustainability. According to Persistence Market Research, the sports equipment industry is anticipated to reach $178.5 billion by 2033 with a 6.5% compound annual growth rate from now until that year. Businesses and organizations can continue to capitalize on the growth of the sports and fitness industries by developing revolutionary equipment for both professional and recreational sports markets. Innovations such as PitchCom have already proven their worth by speeding up play during baseball games and adding more integrity to the game by eliminating sign stealing. Baseball is a great case study for the argument of bringing innovations to the sports industry, as the sport has traditionally been so resistant to change. But even minor technological implementations have brought improvements to the product in just a short period.

ADVANCES IN SPORTS MEDICINE AND WEARABLES

WHAT IT IS

With intense competition comes the risk of injury. Unfortunately, it is not possible to avoid, yet companies are developing a host of technologies and wearables to try to proactively reduce injury when possible, and provide new methods for more reliable diagnosis and treatment in the face of inevitable injuries.

HOW IT WORKS

Nextiles is a smart fabric technology company that focuses its products on athletes. The brand combines flexible electronics with proprietary sewing technology into fabrics using Bluetooth connectivity to measure mechanical changes, primarily to improve athletes' techniques and reduce the risk of injury. Notus Labs also has the ambition of reducing injury through wearable devices. The Notus One is about the size of a quarter and provides noninvasive real-time monitoring of heart rate, core temperature, and player movement. With its integrated platform, Notus can help prevent heat-related injuries. When injuries cannot be prevented, Indian startup NxtQ aims to revolutionize physiotherapy using wearable sensors from Movella DOT. Using these sensors, NxtQ gathers important data for physiotherapists to administer remote diagnosis and treatment. NxtQ algorithms also help interpret data and aid in diagnosis. Madrid-based company ThermoHuman is pushing for the adoption of thermographic technology in the medical departments of top European soccer clubs. By using thermographic cameras to detect areas of heat and pressure in the body, this technology can provide insights for injury diagnosis and treatment through fast and noninvasive methods.

WHY IT MATTERS

Sports are getting faster, and the risk of injuries is becoming greater. Over the course of 13 seasons, the average number of injuries for all four major North American sports was 62.49 injuries per 100 players per season, according to the journal Nature. Sports-related injuries have impacts on health care, creating potential cost burdens, and in extreme instances have harmful long-term physical and psychological implications. However, advancements in sports medicine and science in conjunction with technology such as wearable devices can help the industry keep pace with the rates of injury.

The primary concern is maintaining long-term health and vitality for the athletes themselves. But the longer players are out, the more significant their impact on team performance and potential to impact business performance. This is especially the case for star players missing significant time in the NBA, as individual players can have a greater influence on the outcome of games. Teams and organizations have a vested interest in preventing injury and expediting recovery time when injuries are unavoidable.

Significant opportunities exist for companies to explore preventative measures as well as post-injury rehabilitation, especially as the sports medicine market is predicted to reach $7.2 billion by 2025, according to Allied Market Research.

SCENARIOS

SCENARIO YEAR 2034

What if automated platforms democratized sports?

If Elliott Sartorius had been born during any previous generation, the likelihood of him becoming the world's most prominent soccer player would have been near-impossible, due to his family's poverty. But thanks to automated scouting and coaching platforms, Sartorius discovered that he had a natural, yet raw, talent for the game of soccer. At a young age, he used the CoachU platform, which assessed his natural ability and mental acumen for the game of soccer, and indicated he excelled at all levels. Through motion capture technology, CoachU gave Elliott virtual and augmented suggestions and recommendations to enhance his game before he developed any unhelpful habits at a young age. In his teenage years, right before his eligibility to go pro, CoachU offered Sartorius an option to mutually benefit himself and his fledgling fan base. Through fractionalized investments, his fans could essentially buy stock in his athletic career, helping Sartorius overcome the financial hurdles that would have previously limited his involvement in the game at such a high level. By believing in himself (or believing in the assessment from CoachU) Sartorius rose to stardom, winning lucrative paydays for both himself and his early supporters.

IN THE OFFICE
TEAM/BUSINESS MANAGEMENT

COMMITMENT TO SUSTAINABLE SPORTS

WHAT IT IS

As climate change persists, sports play the role of both victim and villain. Sports teams and organizations are beginning to lead with their actions by implementing programming and operations that result in the use of less carbon. These measures will be crucial to ensure that sports remain viable for years and decades to come.

HOW IT WORKS

Across the world, many sports are going greener. IndyCar has adopted several eco-friendly alternatives to traditional practices in an attempt to reduce environmental impact. That includes using 100% renewable racing fuel—the second-generation ethanol derived from sugarcane was developed by Shell and Raizen and has led to a 60% reduction in greenhouse gas emissions. IndyCar has also adopted Firestone tires made from sustainably sourced materials, which are recycled after use. Beyond IndyCar, the racing industry has moved toward electric and emissions-efficient hybrid alternative-energy vehicles, with Formula E leading the charge. In Seattle, Climate Pledge Arena, the home of the NHL's Seattle Kraken and the WNBA's Seattle Storm is Zero Carbon certified by the International Living Future Institute. This third-party certification highlights highly energy-efficient buildings designed to fully account for their carbon emissions impacts, and requires that 100% of the energy tied to the project must be offset by renewable energy sources. Climate Pledge Arena also includes rainwater harvesting to support resurfacing the hockey rink ice and a zero-waste approach. German soccer club Bayern Munich is partnering with the Schwarz Group in a bid to enter the circular economy. Under this partnership, the environmental service provider PreZero will oversee all waste management at the club's facilities. The mayor of Paris announced the city will prohibit single-use plastics during the 2024 Olympic Games as a significant step toward addressing plastic pollution.

WHY IT MATTERS

David Goldblatt, author of "Playing Against the Clock," has identified sports as both a victim of and contributor to the climate crisis. Climate change has negatively affected sports and individual athletes in numerous ways. In 2020, poor air quality from wildfires led many tennis players to withdraw from the Australian Open. During the 2021 Tokyo Olympics, athletes passed out and faced threatening health issues because of exorbitant heat. The UN Department of Economic and Social Affairs projects that a quarter of England's football stadiums (23 of 92) will be partially or totally flooded every year by 2050. In a 2018 report by the NHL, the league acknowledged that the climate crisis could endanger the sport's heritage of being played outdoors on frozen ponds, but issues will also come with the increasing difficulty of maintaining indoor ice rinks with extreme temperature increases.

At the same time, Goldblatt estimates the sports industry is responsible for potentially emitting 300-350 million metric tons of carbon dioxide per year. Creating the concrete needed to construct stadiums and arenas and producing the fabric for sportswear are also major contributors to carbon emissions. The onus is on the industry to make meaningful change, and it is in a unique position to galvanize action: Its broad social platform can be a strategic tool to influence attitudes and perceptions. Beyond this, sports can also serve as the testing ground for new innovations. IndyCar is an example of taking learnings from the track and using them in road-going products.

SURPRISING MERGERS AND ACQUISITIONS

WHAT IT IS

A series of mergers, acquisitions, and new partnerships are having a seismic impact on the world of sports. These new institutions will have a major effect on how the business of sports is conducted in the future, how athletes are paid, and how fans access the events.

HOW IT WORKS

In June 2023, the PGA Tour and LIV Golf announced their plan to merge commercial operations under common ownership. After some confusion, PGA clarified it would be staying intact as a separate, commercial entity underneath a new structure. This new association will include the Tour's commercial assets, the European DP World Tour, LIV Golf, and other golf-related commercial businesses of the Saudi Arabian Public Investment Fund. This announcement caught the world by surprise because of the previous hostile relationship between the two leagues. A similar situation happened in women's professional hockey, where for more than four years, the Premier Hockey Federation (PHF) and the Professional Women's Hockey Players' Association (PWHPA) were unable to come to an agreement that satisfied both sides. In July 2023, Mark Walter, owner of the Los Angeles Dodgers, revealed that his company had acquired the PHF and shortly after, ceased its operations. The PWHPA has now ratified a collective bargaining agreement with Walter's group for the creation of the Professional Women's Hockey League (PWHL) consisting of six North American teams that will replace the PHF. In April 2023, World Wrestling Entertainment (WWE) and Ultimate Fighting Championship (UFC) announced their merger, creating a new publicly traded company under the control of Endeavor Group. Endeavor will own 51% of the new combat sports and entertainment company, while WWE shareholders will retain 49%.

WHY IT MATTERS

Before PGA and LIV's announcement, 11 players had filed an antitrust lawsuit against the PGA Tour alleging that it used its position as a monopoly as an advantage over the competition. This caused the PGA to countersue LIV Golf on the grounds it was interfering with player contracts. With the announcement of this partnership, members of Congress are exploring whether the merger would actually violate antitrust laws.

If the partnership does get past this obstacle, it has dissidents for other reasons: Some say this is an attempt by the Saudi regime to "sportswash" its reputation in exchange for tens of millions of dollars. Undoubtedly, the merger will result in significant monetary backing for the sport, and serves as a signal of a much larger Saudi presence in American sports in the future. As for the players themselves, this could increase their global prominence, giving them opportunities to earn more through endorsements. But, ultimately, such a merger could also enable the association to pay the players less money as it exerts more control.

Regarding the merger of UFC and the WWE, ultimately, it gives the organizations more influence and power, resulting in a new business worth a combined $21.4 billion. Leadership from both organizations believe it will allow for better negotiated broadcast deals while keeping costs down for viewers. Combining two similar, but ultimately disparate, organizations could benefit the organizations, employees, and fans.

ALTERNATIVE LEAGUES AND ASSOCIATIONS

WHAT IT IS

Investors are showing unprecedented interest in organized sports. This sometimes results in new leagues that mimic traditional associations but offer new value propositions, or in other instances a restructuring of long-standing organizations to ensure their prolonged success.

HOW IT WORKS

In a more controversial move, Australian entrepreneur Aron D'Souza is launching the Enhanced Games. It is a primarily Olympics-style competition with one major difference: Athletes are allowed and encouraged to use performance-enhancing drugs. D'Souza plans to hold the inaugural games in December 2024, featuring sports like track and field, swimming, weightlifting, gymnastics, and combat sports. In golf, Tiger Woods and Rory McIlroy are leading a new venture. The TGL is a high-tech, indoor golf league operated by TMRW Sports in collaboration with the PGA Tour. This tech-driven competition will consist of 18 PGA Tour players, forming six teams of three for 15 regular-season matches, then semifinals and finals. Each match will occur in a high-tech facility. After talking to 50 different European clubs and stakeholders and concluding that European football is under threat and in need of change, A22 Sports Management is developing an 80-team seasonal competition called the European Super League. This merit-based league comes as an alternative to a breakaway Super League that was announced in 2021 led by 12 clubs including Real Madrid, Barcelona, and Juventus.

WHY IT MATTERS

It is no small endeavor to develop a new sports league. However, with a distinct and different value proposition, a startup league could offer something new. The TGL offers a unique alternative to traditional golf leagues and has outlined its distinctive approach in its business strategy, which includes creating franchises centered around cities and involving prominent individuals as stakeholders. Despite hosting its events exclusively in a new arena in Palm Beach, Florida, the TGL is making a deliberate effort to establish strong connections with specific cities, setting it apart from its competing golf leagues, but taking a page more directly from traditional sports franchises.

The controversial Enhanced Games probably will not rival the Olympic Games anytime soon, but D'Souza justifies it with the ulterior goals he hopes to achieve through the institution. He has expressed strong interest in exploring the boundaries of human achievements, ultimately envisioning individuals in their 40s, 50s, and 60s breaking world records. D'Souza sees performance medicine as a pathway to optimizing anti-aging technologies for general use.

The proposed European Super League is a bit more complicated. Through the original 12 team proposal, smaller teams would be at a severe disadvantage. However, the 80 team version could provide the foundation for the financial support the entire football ecosystem needs in order to survive and succeed.

ADVANCED ANALYTICS FOR SCOUTING TALENT

WHAT IT IS

Advanced analytics have increasingly been used over the years to inform coaching decisions. But now, artificial intelligence is generating new insights and analysis for scouting potential and established talent at a level that was previously unimaginable.

HOW IT WORKS

Plaier aims to revolutionize player scouting by using AI to conduct real-time analysis of soccer team playing styles and rosters. The outcomes are correlated with data on over 100,000 players stored in the system, with their abilities weighted in relation to the specific needs of the club seeking new talent. Through this systematic approach, the AI system leverages historical data to make predictions. The Chicago Blackhawks are undergoing a significant internal overhaul of their franchise, starting with the development of an app called Madhouse. This app operates as a central nervous system providing comprehensive insights into hockey players, including their playing history, statistics, scouting reports, interviews, and personality traits. Major League Soccer (MLS) has partnered with London-based startup Ai.io to deploy AI-powered tools for player recruitment, allowing aspiring players to be scouted for free. Players can download Ai.io's AiScout app and complete assessments and drills on their mobile phones. The app will analyze their skills, and the MLS will evaluate the players through the generated data. Those with high scores will have the opportunity to train with MLS teams in the US and Canada. Startup Sports-Visio uses computer vision and deep learning applications to capture footage and action from basketball players and automatically generate statistics and highlights.

WHY IT MATTERS

Using a constellation of technologies such as computer vision, deep learning, and other AI applications, coaching staff can greatly benefit by making more informed decisions about their players and personnel. These network technologies are merely tools and will not immediately replace decades of institutional knowledge or experience from tenured coaches, but they can add supplemental insights and analysis, and help coaches make personnel decisions more quickly and efficiently. There is the threat that such systems will not provide reliable information and coaches could be hesitant to adopt these new technologies, but as the Moneyball phenomenon has indicated, those who first master new forms of analytics will have distinct competitive advantages. Ultimately, though, the use of AI in sports and scouting will require substantial investment and careful integration.

Such technologies could help reduce biases that naturally creep into decision-making, which is what the Blackhawks hope will happen with the implementation of Madhouse. This benefits the organization, but it also benefits the players. With the use of Ai.io, MLS decision-makers can choose to scout players based on objective data, rather than just opinion. This could potentially serve as a democratizer, giving disadvantaged players a chance to have their talents and skills considered, ultimately evening the playing field.

1ST YEAR ON THE LIST

UNIQUE AND INNOVATIVE PARTNERSHIPS

WHAT IT IS

While sports sponsorships and partnerships have essentially existed since ancient times, a series of unique and innovative collaborations are creating synergies and resulting in increased exposure through the unlikely pairing of brands and sports teams.

HOW IT WORKS

In 2023, e-commerce company Zappos.com partnered with the exhibition baseball team the Savannah Bananas to become the official title partner and exclusive footwear partner for their Banana Ball World Tour. The Bananas have traditionally had an ad-free experience, and this partnership evolved due to Zappos' strong customer-centric sensibilities. The partnership aims to merge fashion and sports, promising an exciting and unexpected experience for fans through a series of pop-up activations during the 33-city tour. Similarly, Spotify and FC Barcelona announced a long-term partnership during the 2022-2023 season. Under the agreement, Spotify is both the main partner of the club and its official audio streaming partner. FC Barcelona updated its team shirts with the Spotify brand and rebranded its stadium as Spotify Camp Nou. This unique partnership attempts to connect music and football with the goal of creating a global community of fans and artists. Spotify uses this partnership to spotlight artists and creators, including in-stadium elements to showcase artists to the global TV audience during matches, using geo-targeting to highlight different artists in different markets. In this effort to showcase artists, FC Barcelona honored Canadian performer Drake's achievement of reaching 50 billion streams on Spotify by featuring his logo during a match against Real Madrid.

WHY IT MATTERS

Sports sponsorships and partnerships are as old as time. They can be traced back to ancient Rome, when gladiators relied on the patronage of wealthy individuals to support their training. The first recorded sports sponsorships took place during the 1896 Olympic Games. Since then, these types of partnerships have evolved drastically and dynamically to influence marketing strategies. In that time, these strategies have become more formulaic, but brands are exploring new ways to leverage the model.

The partnership between Zappos and the Savannah Bananas aims to redefine brand culture and provide exciting experiences for fans of both brands, even those disillusioned by traditional advertising models. In a different fashion, the partnership between Spotify and FC Barcelona, with the inclusion of Drake, presents a refreshed method for catering to younger audiences and leverages three major platforms for cross-promotion. FC Barcelona has repeated this initiative with Spanish singer and songwriter Rosalía. The brands have reported that this strategy has helped both the club and the artist reach new audiences. Searches for Rosalía on Spotify were reportedly up a few hundred percent, and the club received half a billion impressions from Rosalía being broadcasted across their channels.

1ST YEAR ON THE LIST

GEOPOLITICS OF SPORTS

WHAT IT IS

In sports journalism, there has been the common refrain to "stick to sports" rather than using platforms to provide political or cultural commentary. However, it is important to recognize that sports and politics have always intersected, and this complex relationship can have significant geopolitical ramifications.

HOW IT WORKS

While the World Athletics Council has loosened previous restrictions levied on Russian and Belarusian athletes based on doping allegations, the Council has now excluded the athletes from its events indefinitely based solely on Russia's invasion of Ukraine. In contrast, while the International Olympic Committee (IOC) will not formally invite Russia or Belarus to the 2024 Olympic Games, they may permit Russian and Belarusian athletes to participate as "individual neutral athletes," but not as representatives of their respective countries. If the IOC allows this, backlash could come from Ukrainian athletes in the form of boycotting the games.

In April 2023, Venezuela hosted the Alliance for the Americas Games after a 12-year hiatus. Eleven countries participated in the event, including competitions such as boxing, gymnastics, bodybuilding, swimming, chess, and dominoes. Participating countries consisted mainly of Latin America and Caribbean nations; however, Russian athletes were invited and allowed to compete under their nation's flag. For Russia, this could represent a symbolic victory over the perceived aggressive Western campaign to cancel Russian sports, and a means to strengthen their international ties.

WHY IT MATTERS

Sports and politics have a long-standing relationship that cannot be ignored. Governments often use sports as a tool to address various challenges such as economic growth, diplomacy, and natural resource management. However, recent events have highlighted how sports can also be utilized for geopolitical posturing. The controversy between Russia and Ukraine is a prime example of how sports can affect many stakeholders, including organizing bodies, media outlets, businesses, and nongovernmental organizations. Decisions regarding this conflict and how they impact sports have been complicated. Critics argue that athletes should still be allowed to gain experience, showcase their skills, and compete on a global scale. Additionally, it can be argued that restricting participation in these international events impacts the integrity of the competition, as this limits best-on-best competition. However, blindly allowing such participation is at best a tone-deaf response to the severity of the actions happening in Ukraine, and at worst, a flat-out insult to Ukrainians. While some athletes may want to focus solely on the athletic aspects of these competitions, sports inevitably continues to be a platform for political strategy.

MORE INCLUSIVE AND ACCESSIBLE SPORTS

WHAT IT IS

Sports have not always been the most consistent drivers of social and cultural change, but the industry is now transitioning to address inclusion and accessibility at all levels, using technology and systemic change to usher in new experiences for fans, athletes, and personnel in sports management.

HOW IT WORKS

Sports management teams and organizations are working toward inclusivity and accessibility for players and fans. In partnership with Special Olympics Australia and Playbk Sports, Gymnastics Victoria has created an online course called "Creating a Positive Experience for Athletes with Autism in Gymnastics." The course equips gymnastics coaches with evidence-based techniques to enhance the participation experience for athletes with autism, and is widely accessible through Special Olympics Australia's online learning platform. The Escoita App, created by AR-MIS Digital Sport in collaboration with Jesus Suarez Lopez, provides a complete sports event experience to users with partial or complete vision loss, regardless of the sport. The app offers real-time audio description, reducing the delay between the event and the narration. The goal of Escoita is to improve user experience, encourage inclusivity in sports, and foster a sense of community among fans. But to achieve true inclusivity in sports, diversity and inclusion must also happen within management and internal hiring. The WNBA is recognized as a leader in promoting diversity and inclusion, with diverse representation from ownership to coaches. The league consistently earns top scores for its racial and gender hiring practices among professional sports leagues. Among men's leagues, both NBA and MLS have improved their racial and gender hiring practices. However, the NBA leads with more people of color in general manager and coaching positions, as well as more women in senior management roles.

WHY IT MATTERS

Sports organizations have a unique opportunity to advance inclusivity and accessibility through their platforms. By dismantling cultural and social barriers, they can serve as catalysts for social change. However, it is incumbent upon these institutions to ensure that their efforts toward inclusion encompass all forms of diversity, including race, culture, gender, religion, and disability. This is vital to promote acceptance and human rights, and eradicate discrimination in sports. While technology may alleviate some inclusion challenges, it can also lead to unintended consequences. FIFA, for example, faced backlash for its tech-driven accessibility ticketing allocations, which ironically left some fans feeling ostracized and marginalized. To prevent similar missteps and foster inclusivity, sports organizations need proper implementation and execution. However, genuine progress can only happen if there is a systemic dedication to initiatives that yield results, starting at the leadership level. Such leadership can transform sports into a more inclusive and empowering field for all, impacting the fan, athlete, and employee experiences.

SCENARIOS

What if consolidation was inevitable?

It was a seemingly normal Wednesday afternoon when Major League Baseball and Major League Cricket (MLC) shocked the world by announcing they would join a collaborative venture called Major League Entertainment. The properties will still maintain their names underneath the new umbrella company, and the leagues will not compete against each other during their respective regular seasons. However, they will host two interleague exhibition games a year featuring all-stars from each league. This cricket match and baseball game will be hosted in neutral international sites in iconic locations in an attempt to build and grow international audiences. The joint venture was precipitated when MLB's position was no longer tenable. Over the years, It has lost too many fans to remain a sustainable entity. However, the league still had its brand reputation and legacy to give it credence, something that MLC had not yet established. MLC, however, was better positioned as it continued gaining national and international interest. After considerable deliberation, both leagues agreed to the deal in principle. More details should shed new light on this astonishing joint venture in the coming weeks and months ahead.

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SPACE

Future Today Institute

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TOP HEADLINES

Access to space is expanding, but challenges persist due to investment constraints, geopolitical tensions, and threats from a crowded orbit.

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The race to the moon is heating up

Who can establish a base on the moon first? The highlight of recent successes and failures include India's landing on the moon's south pole.

02

Space junk is still a threat

SpaceX's Starlink satellites performed 25,000 collision avoidance maneuvers in six months, showing the continued need for innovative solutions.

03

Distrust among the US and China extends into space

China has accused the US of militarizing space, while the US fears that China will use electronic warfare jammers to target US satellites.

04

Countries and companies rush to develop and bolster space capabilities

Saudi Arabia, Scotland, and New Zealand are all increasing space capabilities while NASA's partnership with startups will further its moon pursuits.

05

SpaceX's busiest year yet

In 2023, SpaceX conducted over 90 orbital launches, breaking last year's record by 29. The company also made strides on its Starship program, with the first two test flights ending in explosions but achieving partial success.

STATE OF PLAY

The space economy is a series of contradictions.

Space exploration is entering a new era defined by fresh geopolitical rifts alongside the rise of new spacefaring nations. While the US and Russia unwind once-productive cooperation on projects like the International Space Station, this space race 2.0 sparks rapid capabilities development. Past rivalries yielded innovations in integrated circuits, memory foam, solar technologies, and more. New friction may now drive the next wave of space-enabled advances. This contemporary competition, however, is not just a replay of past dynamics. It brings into play a broader constellation of actors, including smaller nations and private enterprises, all enabled by the decreasing cost of space access. As space access becomes cheaper, more countries can realistically launch their own missions. India and Japan recently landed lunar rovers, joining an exclusive club. With more diverse space blocs taking shape, we may see new models of collaboration between secondary space powers.

Parallel to the geopolitical shifts is a burgeoning commercial space ecosystem now feasible given reduced launch costs. Microgravity research and development, space tourism, and asteroid mining represent trillion-dollar opportunities. As these space industries mature, we can expect related economic and technological ripple effects.

The enduring debate over humanity's future direction—whether to prioritize our ventures into space or focus on Earth's pressing needs—continues. Billionaire explorers like Jeff Bezos and Elon Musk champion the cause of space exploration, not merely as a pursuit of curiosity but as a necessary step for human survival. They argue for the establishment of human presence beyond Earth, envisioning space as a sanctuary that could ensure humanity's continuity against existential threats. As Carl Sagan observed, "Since, in the long run, every planetary civilization will be endangered by impacts from space, every surviving civilization is obliged to become spacefaring—not because of exploratory or romantic zeal, but for the most practical reason imaginable: staying alive." Sagan's words remind us that the journey to space transcends mere adventure or ambition. Investing in space exploration and planetary science is not just about the pursuit of knowledge or the expansion of human presence into the cosmos; it's a critical step in ensuring the long-term sustainability and survival of humanity.

KEY EVENTS

APRIL 14, 2023

Mission Sets Off to Probe Jupiter's Icy Moons
Europe's JUICE spacecraft begins its eight-year odyssey to Jupiter, targeting moons like Europa in the quest for extraterrestrial life clues.

JUNE 28, 2023

Universe Permeated with Gravitational Waves
New measurements reveal a cosmic background hum of low-frequency gravitational waves, confirming Einstein's century-old prediction and expanding our understanding of the universe's fabric.

AUGUST 2023

Lunar Highs and Lows
India's Chandrayaan-3 lands on the moon's south pole as Russia's Luna 25 crashes.

MAY 1, 2023

James Webb detects water vapor
JWST discovers water vapor on an exoplanet 26 light-years away from Earth.

JUNE 29, 2023

Virgin Galactic launches
Virgin Galactic successfully launches Galactic 01, its first commercial space flight.

LIKELY NEAR TERM DEVELOPMENTS

UNLOCKING POTENTIAL IN SPACE

When it comes to space exploration, there are never any guarantees. Missions are often delayed, and the complex nature of space travel often results in the failed execution of even properly laid plans. A wave of transformative developments will make our space-based futures look brighter, however. Based on near term developments and milestones, we will have more certainty on the viability of certain technologies such as asteroid mining, in-situ resource utilization, and space-based manufacturing. We will achieve new breakthroughs, placing humans in new environments. Additionally, we will unlock new mysteries and potentially learn more about our origins.

Space Manufacturing Takes Off

With significant interest from government organizations such as NASA, combined with the engineering know-how of startups like Redwire and Varda, the industry will soon know the viability of manufacturing in space and the true benefits of working in microgravity.

Asteroid Mining Viability

Asteroid mining in and of itself will not be a near term development. However, we should know more about its viability as startups like AstroForge have reestablished their interest in the activity and have insightful missions planned.

ISRU on the Moon

As a demonstration of oxygen production on Mars by NASA's MOXIE has shown, in-situ resource utilization (ISRU) is crucial for space exploration. In due time, a demonstration of oxygen or water production will take place on the moon.

Humans on the Moon

NASA's Artemis program has its sights on sending humans back to the moon and plans to do so by 2025. This along with the recent flurry of lunar activity, including India's unmanned Chandrayaan-3 landing, expect humans to be there again soon.

New Discoveries by the JWST

Since its successful deployment in space, the James Webb Space Telescope has continued to uncover new revelations and inspiration. The JWST will continue to discover more about space, potentially giving us new clues about our origins.

Affordable re-entry

Expect a rise in companies focused on cost-effective return vehicles and methods to retrieve goods manufactured in space. If viable, this point-to-point space delivery and off-Earth industry promises immense expansion for commercial interests.

11 MACRO SOURCES OF DISRUPTION
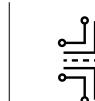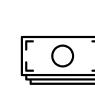
| Technology | Media & Telecom | Demographics | Environment | Government | Public Health | Education | Geopolitics | Infrastructure | Economy | Wealth Distribution |

WHY SPACE TRENDS MATTER TO YOUR ORGANIZATION

Support for disaster preparedness and management

Space-based technologies play a critical role across the entire disaster management cycle. This includes prevention, preparedness, early warnings, response plans, and reconstruction. Predictive modeling can warn of potential threats, and provide information that's critical for assessing risks of entering new markets or providing new services.

More resilient and revolutionary supply chains

Space can impact supply chains in two fundamental, yet dramatically different, ways. First, satellites used for Earth observation can help pinpoint the location of goods throughout supply chains, and help by proactively protecting key parts. Also, in the future, a company's supply chain could extend to space, as space factories become more viable.

Spillover technologies are there for the taking

Technology used in the Hubble Telescope has improved technology for cancer detection in women. Eye doctors are now using technology from the James Webb Space Telescope to help improve human eyesight. Other spillover technologies from space exploration could already exist and provide innovations for other adjacent industries.

Capitalize on the interests of the public sector

The new space race shows no signs of slowing down. Governments will continue to invest more of their budgets in the space industry to maintain competitive advantages. There could be opportunities to win government contracts that aren't necessarily grandiose in nature—such as new applications for project management, not just engineering new rockets.

Responsible orbital activity impacts everyone

At first, our crowded and increasingly unsafe orbits could seem to just be a threat to organizations operating in the space economy. However, this is a risk for everyone, as so much of our connectivity and navigation systems rely on space. Advocating for responsible orbital activity should be something we all invest in.

Existential threats create business opportunities

There is an enormous economic opportunity to clean up Earth's orbit. Unfortunately, we are the culprits responsible for creating this mess. Our space junk dilemma mirrors our current climate crisis. The stability of safe space travel is decreasing, and we must rely on the market to reverse this trend.

OPPORTUNITIES & THREATS

Threats

As long as regulations remain outdated, there's a risk of countries operating kinetic-based anti-satellite weapons. These should be a worry for not just governments but companies whose satellites could get caught in the crossfire.

As ground-based lasers become more sophisticated, there is an increased risk of being on the receiving end of a cyberattack. These nonphysical attacks can use lasers to jam or even blind satellites.

With the tense geopolitical environment of space, it could be easy for a country or competing business to mistake a mishap in space as a purposeful attack against them. Some groups might be quick to retaliate.

Space debris poses the most significant space-related threat. In the event of the Kessler Syndrome, not only would satellites be destroyed but we would not be able to leave Earth, preventing us from being a multi-planetary species.

The democratization of space poses the threat to traditional players of not only smaller and more nimble businesses but also less space-established nations. This could upend incumbents' resourcefulness in the face of constraints.

Opportunities

As more people and things travel to space, there's a heightened need for insurance packages. These could cover the traveling individuals, their possessions, or the satellites in orbit.

Counterintuitively, existential threats in space are leading to business opportunities. The industry for deorbiting space junk and reservicing satellites will remain a growth market for the foreseeable future.

As SpaceX gets closer to reaching the limit of meaningful cost improvements for sending rockets to space, a new player could enter the satellite ride-sharing domain and gain some market share.

As sending payloads to space becomes more affordable, new business models have formed, and other alternative business models are yet to be discovered.

As space tourism unfolds, first-mover advantages open up for companies that offer entertainment services to guests. This will be a very niche market and might only benefit actual first movers.

INVESTMENTS AND ACTIONS TO CONSIDER

1

Earth observation technology will continue to improve and reveal new types of data from advanced instruments. As machine learning and artificial intelligence also improve, companies can make the most of these data sets by uncovering new insights for urban planning, insurance, disaster preparedness, and agriculture for urban planning, insurance, disaster preparedness, and agriculture.

2

The space economy will contribute to the burgeoning biomedical revolution. To ensure that our bodies are conditioned and optimized for space, researchers are exploring ways to edit humans' biology. Research breakthroughs will optimize the human body for space travel and improve human experience on Earth. Research breakthroughs will optimize the human body for space travel and improve human experience on Earth.

3

New pharmaceutical regimens will be needed for individuals spending prolonged periods in space, upending the pharmaceutical industry. The environment of space will also transform the manufacturing process for drugs. This presents a domain outside of the space economy where investments ultimately will impact space.

4

In space, gravity is not a constraint like it is on Earth. As space factories and manufacturing become more viable, businesses should explore products that would benefit most from these micro- and zero- gravity environments. Taking inventory of such products today will enable quick action in the future.

5

Mining will be essential for future space missions and a worthwhile investment consideration. While many associate space mining with asteroids, whose possibility is further in the future, the prospect of mining services on the moon looms much sooner. Mining will be imperative for all aspects of space travel and colonization.

6

As the industry of precision agriculture grows, investing during its infancy could pay off greatly. As it becomes more widely adopted, more companies will follow John Deere's lead and partner and collaborate with space-based organizations that specialize in navigation systems.

CENTRAL THEMES

Space Is Essential for Earth

Critics say we should protect our interests on Earth before entertaining the idea of exploring other worlds. However, this is not a zero-sum game. In fact, the benefits of space exploration and research manifest here, too. Much of our communication and navigation systems and architectures are made possible because of satellites and their constellations out in space. Earth observation services are providing us with a level of data we could not achieve on the ground—data that will prove invaluable as we navigate uncertain climate futures. Many of the technologies essential for space travel also have spillover effects, and will serve extremely useful purposes to our everyday lives.

Microgravity's Macro Potential

Microgravity creates an environment for research impossible on Earth, potentially leading to breakthroughs and new inventions. Drug companies and materials scientists see huge potential in conducting experiments aboard orbiting laboratories. Without gravity, they can develop new kinds of pharmaceuticals and advanced materials not possible on Earth. These breakthroughs might transform medicine, telecommunications, electronics, and more. Many companies are already starting small-scale production of space-made materials. As launch costs continue to decline, space research is poised to skyrocket. We expect a flood of experiments as access expands. But what goes up must come down. Secure transportation methods will be needed to return these precious space-produced goods to Earth. Solving this challenge will help commercialize outer space and unlock profits from zero gravity.

Optimized Resource Utilization

While space exploration is a noble and commendable endeavor, it comes with many perils. For one, getting to space is challenging and costly. Once there, the conditions are unforgiving and not very favorable for human life. With all this in mind, space becomes the epitome of human resourcefulness and ingenuity, and these characteristics are absolutely essential for achieving success beyond our planet. Space exploration is essentially a closed system: all resources within it are valuable and their use must be optimized. This manifests itself in a number of technologies or theoretical solutions including reusable rockets, In-Situ Resource Utilization, additive manufacturing that takes advantage of zero- and micro- gravity environments, resources for mining and harnessing materials for building habitats and spacecrafts, water for jet fuels and radiation protection, and oxygen for supporting life. These optimized processes and technology engender components necessary to ensure continued vitality.

CENTRAL THEMES

Democratizing Space

Entering the space industry can be daunting. Creating the systems and technology required for space travel and exploration requires sophisticated engineering and a comprehensive understanding of math and science. Despite the barriers, space is continuing to become more accessible for unexpected countries launching space programs, fledgling startups raising capital to enter the race, and universities and academic programs with no previous experience. Today, you don't have to create technologies or engineer complex solutions to enter the space economy. Turnkey satellite solutions and satellite-as-a-service business models allow small companies, developing countries, or individuals the chance to live out their space interests. Additionally, the increase in private missions and commercial flights to space is encouraging for the democratization of space. In time, these options will become available to a broader audience.

Collaboration Is Key But Murky

Throughout the history of space exploration, collaborations have made impressive feats possible. Private companies might collaborate to create innovative technologies, or work with public-facing institutions that seek their ingenuity and scrappiness. For nations, the matter is more complicated despite instances of countries with shared interests accomplishing shared objectives in space. Sometimes, space collaboration lags behind the geopolitical situations on Earth. For now, Russia is still a member of the International Space Station. But the country's actions on Earth could eventually put a strain on its space activities. Then there's the US and China: If space collaboration could ever be possible for the two countries frequently at odds, this would reap immeasurable benefits for space exploration. However, China seems to be focusing on expanding its own space station, by doubling the size, as an alternative to the NASA-led ISS, indicating limited interest in increasing cooperation. As the race to space intensifies, the line between collaboration and competition becomes increasingly blurred, reflecting the intricate dance of diplomacy and strategic interests in the final frontier.

ONES TO WATCH

Dr. Amy Williams, astrobiologist at the University of Florida, for her insights into Mars' history and potential for supporting life.

Dr. Christopher Mason, professor of genomics, physiology, and biophysics at Weill Cornell Medicine, for his book "The Next 500 Years" and his work on bioengineering humans for space.

Jane Greaves, professor at Cardiff University, for her discovery of phosphine, a potential biomarker, in the clouds of Venus.

Ivo Labbé, research professor at Swinburne University of Technology, for his Nature publication on the six massive galaxies discovered in the early universe.

Dr. Robin Hanson, economist at George Mason University and research associate at Oxford University's Future of Humanity Institute, for his theories on the "Great Filter" and "Grabby Aliens."

Delian Asparouhov, co-founder of Varda, for his work to create a platform for in-space manufacturing, especially related to the development of in-space pharmaceutical production.

Sara Seager, physics professor at MIT, for her research on exoplanet atmospheres, interiors, and signs of life by way of exoplanet atmospheric biosignature gases.

S. Somanath, chairman of the Indian Space Research Organisation, for his leadership and expertise in guiding the Chandrayaan-3 mission.

Dr. Jane Rigby, astrophysicist at NASA's Goddard Space Flight Center, for being named the new senior project scientist for the James Webb Space Telescope mission.

Dr. Ariel Ekblaw, founder of the MIT Space Exploration Initiative, for leading a portfolio of more than 40 research projects focusing on future life in space.

Dr. Nathan Lundblad, physics professor at Bates College, for his research aboard the Cold Atom Lab on the International Space Station.

Dr. Sarah Burke-Spolaor, associate professor of astronomy at West Virginia University, for proving the existence of low-frequency gravitational waves in space.

Dr. Alexandra Navrotsky, director at Arizona State University's Center for Materials of the Universe, for her contributions to thermodynamics and materials science.

Martin Nisser, Ph.D. candidate in the HCI Engineering Group at the MIT Computer Science and Artificial Intelligence Laboratory, for his research in reconfigurable robots.

Gui Haichao, professor at the School of Astronautics, for becoming the first Chinese civilian to fly in space.

Jared Isaacman, CEO of Shift4 Payments, for his commitment to private space missions through the Polaris program.

Bill Diamond, president and CEO of the SETI Institute, for his leadership in the continual search for extraterrestrial intelligence.

Yuri Milner, Israeli entrepreneur, investor, physicist, and scientist, for his contributions to the Breakthrough Listen project and search for alien life.

Dr. Catriona Jamieson, director of the Sanford Stem Cell Institute at the University of California, San Diego, for overseeing stem cell research in space.

Rayyanah Barnawi, mission specialist on the Ax-2 mission, for becoming Saudi Arabia's first female astronaut in space.

Dr. Lisa Carnell, program scientist for Translational Research in NASA's Biological and Physical Sciences Division, for her work related to 3D tissues and microphysiological systems.

Dr. Stafford Sheehan, co-founder and CTO of Air Co., for his research developing a kerosene-based rocket fuel.

Matt Gialich, CEO of AstroForge, for his commitment to exploring the viability of mining asteroids.

Dr. William Blackwell, laboratory fellow in the Applied Space Systems Group at MIT Lincoln Laboratory, for his leadership of NASA's TROPICS project.

IMPORTANT TERMS

CubeSats
This small, square-shaped satellite measures 10-by-10-by-10 centimeters, and typically weighs around 1 kilogram. CubeSats can be utilized individually as single units or in a constellation. They have a wide range of applications, including testing instruments, conducting scientific experiments, facilitating commercial endeavors, and supporting educational initiatives.

The Drake Equation
This probabilistic argument is used to estimate the quantity of active and communicative extraterrestrial civilizations within the Milky Way galaxy.

Fermi Paradox
The confounding situation of lacking definitive proof for advanced extraterrestrial life, despite the seemingly strong probability of its existence.

Great filter
The term introduced by economist Robin Hanson suggests that, regardless of the widespread emergence of life within our galaxy, every extraterrestrial civilization inevitably encounters an obstacle that threatens its own continued existence.

In-situ resource utilization
The extraction, processing, and use of resources found on other celestial bodies like the moon or Mars.

The Kármán line
Established by the international record-keeping organization World Air Sports Federation, this demarcation point distinguishes Earth's atmosphere from outer space. It is defined to be at an altitude of 100 kilometers above the mean sea level.

Kessler Syndrome
This concept, introduced by NASA scientist Donald J. Kessler in 1978, envisions a situation in low Earth orbit where there are so many objects from space pollution that collisions between them trigger a chain reaction. Each collision generates more space debris, raising the risk of additional collisions.

Low Earth orbit (LEO)
A geocentric orbit spanning from approximately 160 kilometers (100 miles) to 2,000 kilometers (1,240 miles) above the Earth's surface. This is typically where human-crewed artificial satellites operate, where their orbital path completes roughly every 90 minutes.

Medium-Earth orbit (MEO)
A geocentric orbit extending from approximately 2,000 kilometers (1,243 miles) to 36,000 kilometers (23,000 miles) above the Earth's surface. Satellites positioned within MEO face an increased susceptibility to potential damage as they are exposed to intense solar radiation. This orbital region hosts a variety of satellites, including global positioning systems and communications satellites. Satellites situated in MEO typically complete an orbit around the Earth in approximately two hours.

On-orbit satellite servicing
The process of refueling, repairing, or maintaining space satellites while they are in orbit.

Orbital space flight
When a spacecraft reaches a trajectory where it can remain in space for at least one orbit.

Space junk
Defunct satellites and other man-made debris in orbit around the Earth.

Suborbital spaceflight
This occurs when a spacecraft travels to space but does not achieve an altitude and velocity resulting in a ballistic trajectory circling the Earth at least once.

SPACE POLITICS

GEOPOLITICAL TENSIONS IN SPACE

WHAT IT IS

Geopolitical tensions on Earth are spilling over into space-based relations among various nations and complicating aspirations to explore beyond our globe. Conversely, as space becomes more active, the events taking place there will undoubtedly impact relations here.

HOW IT WORKS

The International Space Station once personified nation-to-nation cooperation, but that came into question in 2022 when Russia announced it would abandon the ISS by 2024. Since then, Russia softened this declaration and said it will support the station through 2028, but the country will likely still abandon its commitment in the future. As the war in Ukraine continues, space represents a rare avenue where Russia and Western nations still cooperate and collaborate; however, these relations are tenuous at best.

In space, a shifting geopolitical landscape is unfolding. In August 2023, Russia's Luna-25 spacecraft crashed into the surface of the moon's south pole, just a few days before India's Chandrayaan-3 became the first mission to successfully land a craft there. While Russia and India have been partners on Earth, India's display of strength could come at the embarrassment of Russia. In isolation, India's achievement is significant for solidifying its position in a new space race as various groups rush to the moon to take advantage of its resources.

Other notable groups vying for access to lunar resources are the US and China, which have had a colorful past when it comes to geopolitics on Earth and in space. To further complicate matters, both countries have essentially declared space to be a military domain, leaving little hope that the two nations will cooperate on future related space endeavors.

WHY IT MATTERS

Traditionally, collaborative space projects have not always been a clear indicator of geopolitical relations on Earth. But now, it's becoming even more challenging to disentangle countries' relations in space with what's happening on our home planet. Over the years, space pursuits by various countries have mostly had positive implications for research and technology development, but fear persists that space could be used by various world powers for military purposes. Recently, China accused the US of accelerating the militarization of space. Conversely, the US is wary of potential Chinese electronic warfare technology that could potentially deny US space-based communications. Whether or not there is merit to either country's claims, the threat of a new cold war taking place in space is becoming more pronounced. While it could prove to be foolish to actually use space-based technologies to wage war on other nations, different countries could still engage in an arms race to preemptively render their opponents defenseless, mirroring the dynamics of the previous Cold War. This ongoing threat highlights the pressing need for unified and binding international commitments to ensure the safe, peaceful, and equitable use of space.

EMERGING SPACE-FARING COUNTRIES

WHAT IT IS

Multiple factors, such as reduced payload costs, advances in launch technology, and overall lowered barriers to entry, are making the prospect of space exploration more accessible to new figures in the public sector.

HOW IT WORKS

In May 2023, two astronauts became the first Saudi Arabians to visit the International Space Station. This crew included Rayyanah Barnawi, who became the first Saudi woman in space. The Axiom Space's Ax-2 mission signifies the increasing influence that Gulf nations are having on the space economy. Prior to this milestone, another Gulf nation had already left its mark in space: The United Arab Emirates has sent its own astronauts to space, launched spacecraft to both Mars and the moon, and deployed satellites. As for future missions, in 2028, the UAE plans to send a spacecraft to our solar system's asteroid belt to study seven asteroids with the intent of learning more about our origins on Earth. Looking beyond Gulf countries, other new faces are entering the mix. In mid-2023, South Korea's Nuri Rocket completed its third launch, but for the first time carried commercial payloads into space. Scientists from the Indian Space Research Organisation launched next-generation navigation satellite NVS-01, adding to India's fleet of navigation spacecraft and providing interoperability with other countries' global networks. Recognizing the heightened geopolitical risks surrounding space, New Zealand has developed its own space policy, including objectives for growing an innovative and inclusive space sector centered around promoting and protecting its national security and economic interests. The policy serves as an important landmark in New Zealand becoming a space-faring nation.

WHY IT MATTERS

Of the over 70 documented space agencies, as of 2024, 16 possess the ability to launch, while only seven exhibit complete launch capabilities—meaning they can launch and also recover satellites and operate extraterrestrial landing capabilities. South Korea is the most recent country to join this exclusive list but Scotland could also join soon, as construction of Sutherland Spaceport is underway on its north coast. The only continent lacking launch capabilities is Africa, but even this could change soon, as plans exist to build a spaceport in Djibouti over the next five years with $1 billion invested by Chinese company Hong Kong Aerospace Technology. This operation, along with existing space projects, could propel the African space industry to a value of $23 billion by 2026. There is significant economic incentive for new space-faring countries, and as prospects of sending payloads to space become more accessible and less costly, it should come as no surprise to see this trend continue. By expanding their presence in space, these countries will increase their autonomy, allowing them to stand up for themselves and their own interests—whether they want increased monitoring for agriculture programs or more control over telecommunications systems.

GOVERNING SPACE

WHAT IT IS

Both governments and intergovernmental organizations are advocating for responsible space behaviors to avoid a major catastrophe in space. As the space industry becomes more lucrative and enticing, new guidelines are needed to ensure safe and equitable exploration, exploitation, and utilization of space and its resources.

HOW IT WORKS

In 2022, the United States banned direct-ascent anti-satellite (ASAT) missile tests, which can potentially create orbital debris—an action intended to create an international push for more responsible space behavior. At the end of that year, the United Nations General Assembly overwhelmingly approved a resolution to suspend ASAT testing. Despite the nonbinding resolution's immense support, only 13 nations have committed to its precepts. More countries are actively being encouraged to also commit.

When it comes to governing space, many existing initiatives—such as the one mentioned above—are driven by nations' independent interests and concerns. Currently, there is no agreed upon international framework for space resource exploration, exploitation, and utilization—as noted by the UN brief "For All Humanity—The Future of Outer Space Governance"—and no mechanism to even support the implementation of such a framework. The UN hopes that the dialogue and activity surrounding its brief will lead to the development of international norms, rules, and principles to address threats to space and its associated programs and systems. A combination of binding and nonbinding norms have also been proposed to address emerging risks to outer space security, safety, and sustainability.

WHY IT MATTERS

Individual nations, including the United States, have enacted their own resolutions to address activity in space, but such resolutions primarily serve the interests of the nation that proposed them and are only binding for the signing countries. Subsequently, this gives privileges to non-signing parties. The current actions of the United Nations are promising, as they move to implement a set of unified norms for space travel and use, but because some of the norms will still be nonbinding, obstinate countries could continue to make things complicated.

Organizations such as the UN pursuing safer guidelines for space travel need to strike the appropriate balance between properly regulating activities and spurring innovation. As space exploration remains unchecked, there is the increasing threat of debris or a geopolitical quagmire among competing nations. However, a hasty implementation of strict and stringent rules could drastically hamper the progress of bold and daring endeavors to access more of space. Both private and public organizations must prepare for a more regulated industry while also ensuring that the spirit of exploration and discovery that drives humanity's fascination with space is not extinguished.

SPACE DEFENSE

WHAT IT IS

Nations around the globe have a vested interest in protecting themselves from space-related activities. As space systems become more prevalent, countries will naturally become more suspicious of other competing nations, heightening the risk of space-based turmoil.

HOW IT WORKS

President Joe Biden's 2024 budget request increases funding for the US Space Force to $30 billion to meet evolving threats and protect the country's interests in space. The institution has cited the importance of space to everyday life, including GPS navigation and communications. Ultimately, this budget increase marks the US' attempt to keep pace with other countries, namely Russia and China. The US has identified the latter's ground-based lasers as a threat to satellites and plans to transition to proliferated networks of smaller satellites in Earth's orbit to combat the issue. The Space Force has also opened the Commercial Space Marketplace for Innovation and Collaboration to partner with the private sector in acquiring defense technology.

In a historic first, Israel's Arrow 2 missile defense system intercepted and neutralized a ballistic missile beyond the Earth's atmosphere, marking a potential inaugural instance of space-based combat. The system obliterated a suborbital missile launched by Houthi rebels in Yemen, achieving interception above the Kármán line—the internationally acknowledged space boundary situated 62 miles above sea level. This demonstration indicates that conflicts on Earth may begin to extend beyond our atmosphere as well.

Aside from space defense against other countries, planetary defense involves initiatives to monitor and protect Earth from asteroids and other objects that could threaten our planet. Even though NASA's Double Asteroid Redirection Test (DART) happened almost two years ago, we are still learning more about this mission. DART's successful impact with the asteroid Dimorphos altered the asteroid's orbit but led to the creation of a crater that flung debris from the asteroid. ESA's Hera mission, launching in October 2024, aims to study the Didymos binary asteroid and assess DART's impact, providing key insights for future asteroid deflection strategies.

WHY IT MATTERS

As space presents itself as a new Wild West, it will continue to be perceived as a risk to national security, whether those threats come from rising geopolitical tensions and conflicts on our home planet, or from the impending threat of celestial objects that we have even less control over.

When it comes to national defense, space has become critical for myriad reasons. So many space systems have become necessary components of our daily lives. Simple miscommunication among disparate nations can have outsized impacts, potentially leading to the destruction of important communication devices. More overtly nefarious threats exist as evidenced by Russia's cyberattack in February 2022 that left Viasat's KA-SAT modems inoperable in Ukraine. This incident led to other next order impacts, resulting in the malfunction of 5,800 Enercon wind turbines in Germany and other major disruptions to major European organizations. The US Defense Department has vowed to openly communicate US military space activities in an effort to prevent misunderstandings and miscalculations. However, China's decision to not be as transparent complicates matters. Without unified standards and norms, we are just a minor mishap away from nations taking retaliatory measures on perceived space-based threats.

SCENARIOS

Tax Tensions on Mars

The Colonized Habitat Optimization and Mining Co. (CHOAM), operating primarily on Mars and its surrounding Lagrange Orbit Equilibrium stations, mined Martian water ice to support other Mars-based ventures, scientific explorations, and low orbit Earth habitats. Initially incorporated as a Delaware C corp, CHOAM contemplated a paradigm shift in its corporate structure amid the complex milieu of US corporate tax policy. Attracted by the increasingly business-friendly climate of Singapore, and its progressive stance toward space commerce, CHOAM considered reincorporation. Singapore's introduction of tailored tax incentives for space-faring entities promised an advantageous arena compared to the US jurisdiction.

However, CHOAM's interplanetary ambitions are being tethered by the restrictions of US export controls. Navigating through the maze of the International Traffic in Arms Regulations (ITAR) and the Export Administration Regulations (EAR) was no minor feat. To circumvent the challenges of US export controls, CHOAM is ramping up in-situ inputs: By leveraging Martian regolith and other locally sourced materials, the company is extensively employing advanced 3D printing technologies to fabricate tools, infrastructure, and essential operational components. This drastic reduction in its Earth-based dependencies skirts many export control complications. CHOAM's strategic move to Singapore didn't go unnoticed. Other extraterrestrial corporations, grappling with the intricacies of off-world operations under their respective Earth jurisdictions, have begun evaluating potential reincorporation in tax-favorable countries.

1ST YEAR ON THE LIST

DOMESTIC COMPETITION

WHAT IT IS

Having recognized the economic impact the new space economy will have on local economies, select US states and markets are trying to establish themselves as major hubs for domestic operations. Through economic incentives and relaxed regulations, these states will attempt to edge out others to gain a competitive advantage.

HOW IT WORKS

In 2023, Texas Gov. Greg Abott signed HB3447 into law, establishing the Texas Space Commission. This group will allocate $350 million to develop the space industry in the Lone Star State, and will oversee planning, funding distribution, research, and education efforts in the Texas space industry. In a similar vein, Florida Gov. Ron DeSantis signed a bill into law aimed at reducing liability for commercial spaceflight companies, with an ultimate goal of attracting more launch providers to Florida's Space Coast. Under the law's provisions, companies will be granted immunity from liability associated with flight-related injuries or deaths, as long as crew members sign a waiver. Other states have shown they want a foothold in the space industry. President Joe Biden's decision to leave the US Space Command headquarters in Colorado evoked ire from Alabama officials. It was a reversal of a Trump administration decision to relocate the headquarters to Alabama. State officials claim abortion politics played a role in the change, as Alabama Republican Sen. Tommy Tuberville had been blocking military promotions over the Pentagon's abortion policies.

WHY IT MATTERS

In January 2023, Space Florida, the state's aerospace economic development agency, announced that the total economic impact of its aerospace finance and development authority had reached $5.9 billion since 2007. It expects the industry will have an additional $5.3 billion economic impact over the next five years, with an average annual impact of $1.1 billion. Ultimately, Florida recognizes the tremendous economic impact of the space economy and is doing everything in its power to entice more organizations to move or establish operations in the state. The space industry's potential economic impact on local economies is the central driver for the Texas Legislature's committing $350 million to fund and support Texas aerospace and space projects and new economic incentives to draw space companies and space startups to the state. The reaction from the political leaders of Alabama is understandable considering the US Space Command represents the significance, influence, and status of the space industry. The activities of these states underscore one thing: Whoever dominates the space race will dominate here on Earth.

SPACE BLOCS

WHAT IT IS

Despite competition arising from the quest to travel to space, there's also been extensive collaboration. Since the Cold War's end, nations have been forming space blocs—groups of countries joining forces to further their collective interests in space.

HOW IT WORKS

Many consider the European Space Agency—now consisting of 22 nations—to be the first space bloc. One of the newer collaborative blocs is the African Space Agency, which officially formed in January 2023. Despite this union, Russia has tried to entice Algeria and Egypt to join its space program. The Latin American and Caribbean Space Agency now consists of 23 member states, and while no formal agreements have been brokered, China has expressed open support of the organization. Perhaps the most prominent collaborative bloc is the Artemis Accords, drafted by NASA and the US Department of State. This nonbinding multilateral arrangement with other world governments attempts to establish common principles, guidelines, and best practices for the safe exploration of the moon and beyond. NASA's adjacent Artemis program will require significant partnerships with countries and private companies to ensure it sends astronauts back to the moon. In 2023, India, Ecuador, Argentina, and the Czech Republic became the most recent countries to sign the Artemis Accords, marking a significant uptick in space collaboration with the US.

WHY IT MATTERS

Proponents of the Artemis Accords contend that the major tenets act as an extension of the 1967 Outer Space Treaty, to set principles for a safe, peaceful, and prosperous future in space. While a series of protocols to ensure this type of future is necessary, some have a complicated view of the Accords for a few key reasons. Notably, the 1967 Outer Space Treaty is seen as insufficient for governing current space endeavors, and the industry in general could benefit from a new, refreshed set of regulations to moderate activity in space. The treaty also asserts that "outer space is not subject to national appropriation by claim of sovereignty." Forming space blocs could be seen as a strategy for skirting this major tenet: While not claiming sovereignty of the moon or other celestial bodies, these blocs may make the case that their visits to and settlement of the moon are not acts of individual state sovereignty, and thereby not in violation of the treaty.

Opponents of the Accords contend that they are too centered on American and commercial interests, leading countries such as Russia and China to not sign the agreement. Both countries have their own individual and sometimes joint efforts to establish a presence on the moon, and continually seek collaboration with new countries and agencies, fully understanding this mode of operation is necessary to be the leader of the modern space race.

1ST YEAR ON THE LIST

GEOPOLITICAL TENSIONS OVER SPACE JUNK

WHAT IT IS

Space junk refers to the tens of thousands of defunct human-made objects in space, including old rocket parts, dead satellites, and debris from collisions—both accidental and intentional. As more nations operate in space, managing this issue involves addressing concerns of national security, weaponization, and liability.

HOW IT WORKS

About 100 trillion fragments of defunct satellites and spent rockets orbit the Earth. While some of these fragments are monitored, others are too minuscule to be tracked, presenting a considerable danger. Potential collisions between them can create even more fragments. In a phenomenon known as the Kessler Syndrome, these collisions can create a cascading effect, where debris begets more debris in a runaway cycle.

The severity of space debris was highlighted in January 2023, when an old Soviet-era rocket nearly collided with defunct satellite debris, a potential worst-case scenario that could have resulted in thousands of new pieces of debris. The threat is further complicated by irresponsible actions including the deployment of anti-satellite devices. In November 2021, the Russian Ministry of Defense launched an anti-satellite (ASAT) missile, creating a cloud of debris that threatened the International Space Station. Following the incident, the UN approved a resolution against ASAT tests. Meanwhile, tensions continue to brew around North Korea's satellite capabilities, leading South Korea and the US to agree on a joint probe into North Korean space rocket debris. In May 2023, the G7 nations deemed the issue of space debris an "urgent problem" that must be addressed collectively, including research in both orbital debris mitigation and remediation technologies.

WHY IT MATTERS

The escalation of space debris is both a technical challenge and a complex geopolitical issue. Nations possessing advanced space capabilities heavily depend on satellites for core national security functions, like surveillance, communication, and navigation. But satellites extend beyond military applications; from guiding us to our destinations through Google Maps to facilitating real-time financial transactions, commercial satellites are integral to our modern existence. Space debris, consequently, doesn't merely jeopardize national security—it also threatens economic stability and daily lives.

The problem exacerbates if debris from one nation damages another's satellite, invoking questions of accountability and liability. While international space law offers a legal framework, its application can be ambiguous, potentially sparking international conflicts. Like the high seas, space is considered outside the jurisdiction of any one nation, leading to a "tragedy of the commons" scenario. Citing the mismanagement of the oceans as a cautionary tale in the journal Science, a group of scientists recently urged regulators to avoid repeating past mistakes when establishing governance for space.

SCENARIOS

Interplanetary Park System

After more nations started sending spacecraft to land on the moon's south pole through the end of the 2020s, the United Nations finally decided to step in with more stringent and binding resolutions to regulate space travel. The international body had to be done right or risk both private and public operations wrecking the entire space environment. The urgency to put a temporary reprieve on commercial operations on the lunar surface was precipitated when a US-based company's testing equipment interfered with a Japanese rover, which almost sparked an international lunar incident. With commercial operations indefinitely suspended, various organizations were left hanging in the balance as their moon-based initiatives lay fallow.

In a ruse to keep valuable experimentation and lunar-based research moving forward, the US is volunteering its Artemis Program to launch the Interplanetary Park System in an effort to ensure the heritage of space can "be enjoyed today and preserved for tomorrow." Under the proposal, the IPS, through the collaboration of Artemis countries, now numbering 38, will continue its in-situ resource extraction and utilization and other experimental manufacturing methods, but all collected resources will be used for the infrastructure needed to establish monuments and the necessary built environment for IPS programming. Artemis and the IPS pledge to make space accessible to all global citizens of Earth. After establishing the infrastructure that would least invasively allow individuals to visit historical and significant sites on the moon, the IPS plans to explore other potential locations in our solar system to establish additional sites of interest, using lunar resources for fuels and building materials needed for such an initiative.

SPACE INDUSTRY

2ND YEAR ON THE LIST

SPACE FACTORIES

WHAT IT IS

Low earth orbit (LEO) may be a more suitable environment for manufacturing some goods and products like semiconductors and artificial proteins. As orbital transport costs decrease, we may see more companies move specialized production to space.

HOW IT WORKS

Space-based manufacturing harbors immense potential due to the unique conditions inherently present there. For instance, semiconductor manufacturing necessitates an extremely clean, low-pressure environment to avoid contamination. Naturally, the vacuum of space offers these conditions, a fact being capitalized on by companies like Space Forge, which intends to manufacture semiconductors in space. Researchers at MIT have utilized LEO's microgravity to produce intricate "skins" for additive manufacturing. Other efforts include Apsidal's module to manufacture complex glasses and fibers in space, and Varda's successful launch of the first space factory on SpaceX's Falcon 9 to produce pharmaceuticals (discussed in more detail under "Biomanufacturing in Space").

The impact of space manufacturing extends beyond earthbound economies. It's instrumental in establishing sustainable human habitation outside of Earth. Redwire Corp., through a recent NASA contract, is turning this concept into reality with FabLab, an in-space multi-material 3D printer. This transformative tool will empower space crews to manufacture essential items on demand, bolstering the self-sufficiency of future space dwellers and marking a significant leap toward a multi-planetary existence.

WHY IT MATTERS

Space-based manufacturing has the potential to overcome the constraints of gravity and optimize production in ways not possible on Earth. By making goods like semiconductors, organoids, and metal alloys in the microgravity of space, we can customize the manufacturing environment free from gravity's limitations. As climate change disrupts supply chains on Earth, off-planet production offers a resilient backup option, diversifying sources beyond our planet. In-space manufacturing may prove a strategic solution for enhancing supply chain resilience as accelerating climate impacts threaten production on Earth.

Space factories also play a pivotal role in enabling a sustainable long-term human presence in space. They not only reduce our dependence on Earth but also make us more viable as an interplanetary species by drastically cutting costs and risks associated with launching resources from Earth. The International Space Station has been trailblazing in this respect, having 3D printed in space since 2011. This progress toward self-sufficiency shows in-space production is feasible and an essential step toward independence from Earth. It signals a new era enabling deeper space exploration and habitation as humanity transitions to a multi-planetary civilization.

1ST YEAR ON THE LIST

BIOMANUFACTURING IN SPACE

WHAT IT IS

Biomanufacturing in space leverages microgravity to enhance production of biomolecules and materials, like drugs and tissues. It deepens our understanding of biology and aids clinical applications. As we plan for long-term space missions, sustainable in-space biomanufacturing becomes crucial.

HOW IT WORKS

Organoids are tiny, lab-grown models of human organs used to study structure and function. On Earth, gravity flattens organoids into blob-like shapes. But in microgravity, cells proliferate faster and can grow in 3D and better mimic real organ behavior. Space also optimizes organoid development. The controlled environments of space stations further limit contamination risks, creating ideal biomanufacturing conditions.

In 2023, Varda Space Industries launched the first orbital factory dedicated to pharmaceutical production in space. Its inaugural project focuses on assessing the manufacturing of the HIV medication ritonavir under microgravity conditions. However, Varda encountered a regulatory setback after its June launch: While the Federal Aviation Administration approved the launch of the orbital factory, it has not authorized the descent of the recovery capsule, posing a challenge to the startup in retrieving its space-manufactured drug samples. Redwire Space was awarded a 14 million euro contract by the European Space Agency to design a comprehensive facility for tissue engineering and regenerative medicine on the International Space Station. This effort builds on Redwire's existing bioprinting work on the station, including a project to bioprint human knee meniscus tissue. Meanwhile, researchers at the China Space Station have successfully created early-stage blood cells in space for the first time, bringing us one step closer to treating diseases by producing any type of human cell. In this experiment, pluripotent stem cells, capable of developing into any major human cell type, were sent to the Wentian lab module, where they successfully matured into hematopoietic stem cells, the precursors to blood cells.

WHY IT MATTERS

After decades of single-use spacecraft, SpaceX's reusable launch systems have dramatically reduced the costs of accessing space. With biotechnology innovations accelerating in parallel, we have reached an inflection point where biomanufacturing in space is technically possible and may soon make financial sense. For example, growing human organs in microgravity could provide a cost-effective, long-term solution to organ shortages for transplants. Producing biomaterials and pharmaceutical goods in space could lead to scientific breakthroughs or better drugs. Varda's founder explained in an interview that until now, gravity has always been considered a constant. With space biomanufacturing, gravity can now be a variable to sub in and out of experiments. This could revolutionize fields like drug testing and disease modeling by engineering higher-fidelity organoids.

SpaceX enabled cheap launches, catalyzing space research. But achieving orbit is only step one. We also need companies focused on affordable ways to retrieve the results and deliver them safely back to Earth. Reusable reentry vehicles to ferry goods from cosmic factories will require regulatory greenlights. If approved, regular roundtrip transport could accelerate off-planet R&D across sectors. Furthermore, as we venture farther into space, the ability to manufacture biomaterials and pharmaceuticals in situ will become increasingly vital. Transporting all required medicines, medical devices, and even organs from Earth to off-world colonies would be enormously expensive and inefficient. Instead, establishing biomanufacturing infrastructure throughout the solar system can provide colonists with reliable on-demand access to medicines, nutrients, tissues, and organ replacements tailored to local needs.

OFF-PLANET RESOURCE PRODUCTION

WHAT IT IS

Off-planet resource production, or in-situ resource utilization (ISRU), refers to the extraction, processing, and use of resources found on other celestial bodies like the moon or Mars. ISRU aims to make space missions less expensive and easier by reducing the amount of resources needed to be transported from Earth. It's the key for long-term space habitation and deep space expeditions.

HOW IT WORKS

ISRU endeavors are largely concentrated on extracting life-sustaining elements (water and oxygen) as well as providing rocket propellant for return trips to Earth. NASA's Perseverance rover is actively seeking water on Mars, and similar strategies are applied on the moon using thermal extraction. Experiments like MOXIE on Mars have successfully produced oxygen. In recent years, however, the focus of ISRU has extended beyond oxygen and water production. Companies like Air Co., a finalist in NASA's Deep Space Food Challenge, have developed a method to convert carbon dioxide, water, and yeast starter into protein-rich yeast using a process that simulates plant photosynthesis but uses astronaut breath. This yeast can then be converted into a variety of food forms, potentially supplying long-duration space missions.

Blue Origin, funded by a $34.7 million NASA contract, is "Blue Alchemist"; this ISRU project is a reactor that separates oxygen from lunar regolith, leaving behind materials for solar cell construction, while the oxygen could provide breathable air. Zeno Power and Redwire also won contracts that help missions to live off the lunar land. Zeno Power is converting heat generated from decaying radioisotopes into electricity to provide nuclear power on the moon. Meanwhile, Redwire is building roads and landing pads on the moon by utilizing a microwave emitter to transform lunar landscapes into solid surfaces.

The ESA is also experimenting with methods to create roads on the moon. In 2023, the agency successfully used a laser to melt simulated moondust. The goal was not just to pave roads for future on-moon transportation but also as a practical response to keep lunar dust at bay, which has caused issues in the past by clogging equipment during the Apollo era.

WHY IT MATTERS

Consider this analogy: If you're a New Yorker planning a vacation in Europe, you wouldn't pack all the water you'd need for drinking and bathing into your suitcase. Not only would it be exorbitantly expensive, but it's also highly impractical since water is readily available in Europe. The same principle applies to space travel. With starting costs around $6,600 per kilogram, the fiscal burden of taking anything with you is undeniable. Even as SpaceX's reusable rockets strive to bring down these costs, launch costs are still substantial. By tapping into local resources on the moon or Mars, we can significantly reduce the costs and challenges associated with space travel. Simply put, to establish self-sustaining colonies in space, we must utilize local resources. Without ISRU, practical and sustainable life on other planets remains a distant, unattainable dream. It's too costly and risky to rely solely on Earth for the constant supply of life-sustaining resources. To live beyond our planet, we will require more than just the basic survival resources like water and oxygen; we need infrastructure and shelter. Efforts from companies like Blue Origin, Zeno Power, and Redwire will help establish the infrastructure we need for scientific research, colonization, and even industrialization.

1ST YEAR ON THE LIST

THE SATELLITE BOOM

WHAT IT IS

Over the past decade, the number of satellites in space has grown almost sevenfold as costs decreased for building satellites and shipping payloads to space. Turnkey solutions and new business models are allowing smaller companies to enter the market, but to match the demand, new players will need to capture more market share.

HOW IT WORKS

In the early 2010s, only about a thousand satellites were in orbit, mainly because of their high costs. Originally, building a satellite cost $200–$300 million, and launches were around $380 million each. Today, there are over 7,000 active satellites thanks to SpaceX's efforts in reducing launch costs through reusable rockets and ridesharing services. By 2015, launch costs dropped to $275,000 per kilogram, and now range as little as $3,000/kg–$6,000/kg. This affordability has opened doors for entrepreneurs and hobbyists in satellite ventures. However, smaller satellite operators are struggling to get on SpaceX's crowded launch schedule. Despite this, smaller launch companies like ABL Systems, Relativity Space, and Astra Rocket are emerging to meet the increasing demand. For those entering the satellite industry, turnkey solutions from companies like York Space Systems, Blue Canyon Technologies, and Apex Space offer mission design, spacecraft, launch, ground, and operations services. To cater to growing military demand, Lockheed Martin is restructuring its space division and selling technology and satellite parts to align with the booming space sector. For organizations with even fewer resources to spend on this industry, satellite-as-a-service is an increasingly popular business model offered by ISISpace, Loft Orbital, and Spire Global.

WHY IT MATTERS

While rideshare options on SpaceX rockets are showing to be more of a challenge, growth for the global satellite industry is far from slowing down. With growing demand, new players can gain market share. The market for hitching rides on other company's rockets now consists of two broad categories: smallsat constellation developers looking to augment their systems, and startups, universities, and governments planning to send their first satellites to space. Additionally, regions such as Latin America and the Middle East are growing their space capabilities and also contributing to this new demand.

Besides the decrease in cost to both build and launch satellites, two other significant drivers are creating demand in this industry: the need for mobile communications and Earth observation (EO) services. Communications satellites account for the largest and fastest growing market segment. According to Grand View Research, this segment is currently valued at roughly $72 billion and anticipated to grow at a compound annual growth rate of 9.5% from now to 2030. Alternatively, Straits Research predicts the EO market will be worth $13.6 billion by 2030. New regulations will require organizations to report environmental impacts using satellite data. This mandated transparency is expected to create an Earth observation boom, driving innovation of technologies that enable independent tracking of sustainability metrics from space. This industry will have an immeasurable impact on resource and supply chain management as well as urban planning and development—it shows no signs of slowing down.

1ST YEAR ON THE LIST

CONSTELLATION MANAGEMENT

WHAT IT IS

With the meteoric rise of the satellite industry over the past several years, there is increasing need for effective and dependable satellite constellation management solutions. These systems assist satellite operators in optimizing performance while minimizing operational expenses.

HOW IT WORKS

Florida-based Sidus Space offers a full suite of satellite constellation management services. It assists in arranging the launch, ensures all necessary licenses and permits are in place, and handles all aspects of the day-to-day operations once in orbit—including monitoring the constellations' health, adjusting their positions, and making sure they continue to function properly. Engineering services company A.I. Solutions specializes in satellite flight dynamics by providing expertise in orbital mechanics, mission planning, and satellite operations. It's been involved in operating and managing satellite constellations associated with the International Space Station, GPS, Landsat, and the Geostationary Operational Environmental Satellite. Its proprietary FreeFlyer software provides flexible and scalable options for both small and large satellite constellations. It can automate routine tasks and distribute them across virtual machines or cloud instances, providing coverage for constellations consisting of thousands of satellites. FreeFlyer also supports traffic management efforts for these complex satellite clusters. Raytheon's constellation management solutions use a signal ground system and edge processing to enhance data collection speed and accuracy. They employ artificial intelligence and machine learning to extract maximum value from on-orbit assets.

WHY IT MATTERS

Companies that rely on constellations of satellites to run their everyday operations need efficient and dependable systems and services, at minimal operational cost. Advanced signal processing on satellites enables efficient use of available spectrum, with dedicated integrated circuits maximizing capability and efficiency. Phased array antenna technologies create dynamic spot beams, delivering signal power and capacity where needed on the ground. High-bandwidth optical inter-satellite links connect mega-constellations, providing secure, low-latency data backhaul across the globe. From this complex network of technologies, operators can achieve real-time monitoring and notice of issues, consequently reducing possible downtime risk. They also realize efficiencies with optimized fuel usage and decreased maintenance costs. Through analytics, these services can open up revenue opportunities by enhancing satellite coverage and expanding service areas, thereby increasing the number of customers these constellations can serve. Overall, satellite constellation management systems enhance satellite performance, reduce costs, and improve customer service.

1ST YEAR ON THE LIST

MINING

WHAT IT IS

Space mining is the process of extracting valuable resources such as minerals, metals, and water from celestial objects like asteroids, the moon, and other planets. The prospecting, excavating, and extracting of these resources can be used for various purposes including fuel production, construction of habitats, and future space exploration.

HOW IT WORKS

In 2023, the OSIRIS-REx mission successfully returned a sample to Earth from asteroid 101955 Bennu. The spacecraft continued on to a new mission to explore the asteroid Apophis. Meanwhile, scientists hope the sample will offer clues about whether asteroids brought water and other key ingredients for life to Earth billions of years ago. It could also help inform us of available materials for more commercial purposes.
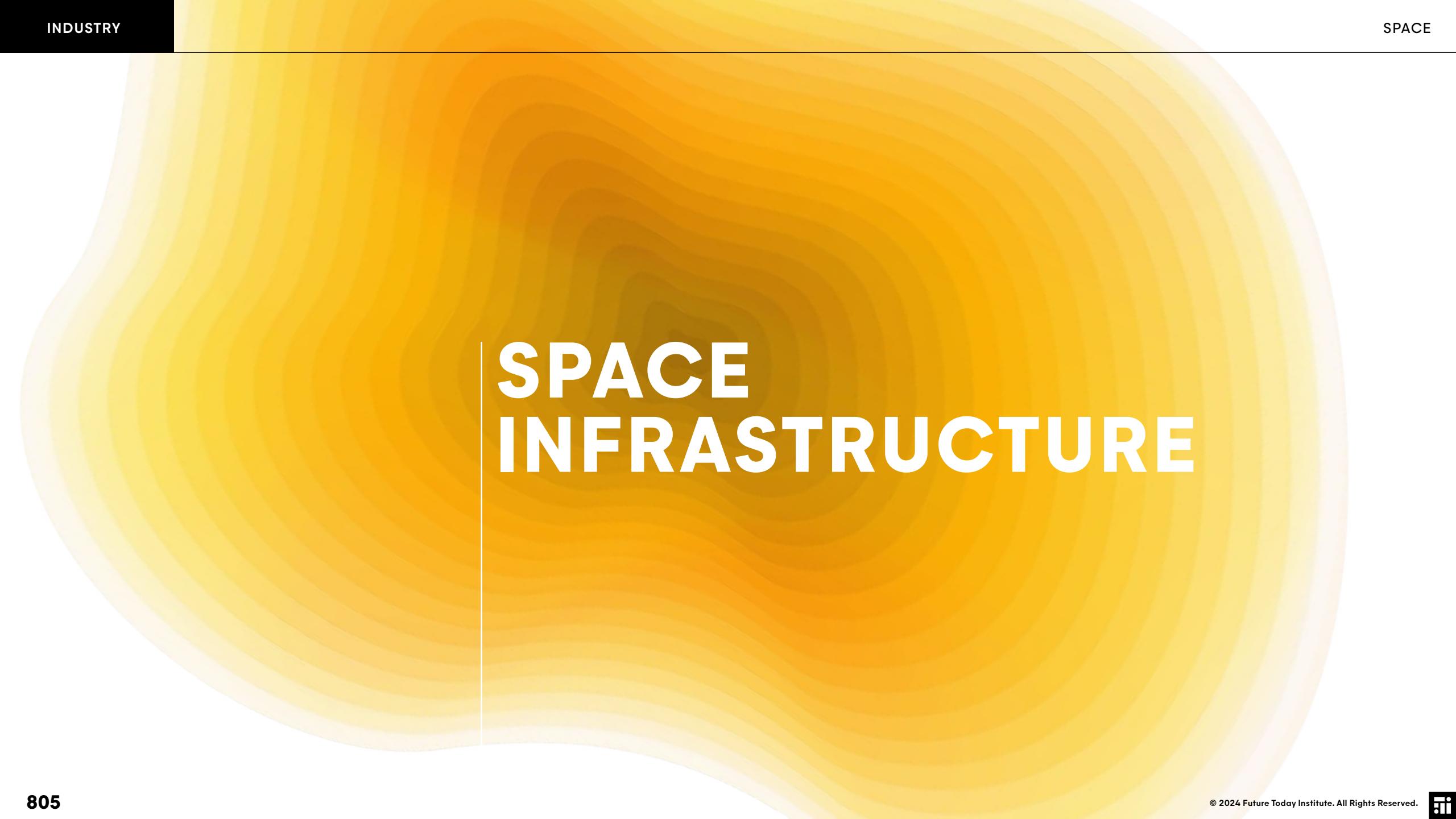
California-based startup AstroForge is embarking on two missions toward becoming the first commercial company to mine asteroids. It plans to use CubeSats on its first mission to test in-situ refining in a zero-gravity environment. The second mission will send a spacecraft on an 8- to 11-month journey to prospect a near-Earth asteroid, which has yet to be publicly identified. Ultimately, AstroForge plans to extract rare minerals from these asteroids and bring them back to use on Earth. Colorado-based Karman+ is focused on creating technology to mine water from near-Earth asteroids. It has identified over a million of these asteroids that could potentially be mined using a model developed through a meta-survey of solar system objects. Asteroid Mining Corp. is also on a mission to prospect, explore, and extract resources from asteroids. It is developing Space Capable Asteroid Robotic Explorers (SCAR-E), a modular hexapedal robotics platform for drilling into asteroids and processing extracted materials in space. TransAstra plans to mine moons and planets in addition to asteroids. By using its optical mining process, TransAstra will use concentrated sunlight to excavate feedstocks for propellant from these celestial bodies.

WHY IT MATTERS

While many space startups have set their mining ambitions on extracting valuable resources from asteroids, our moon will probably serve as a more valuable asset for collecting these resources first. With the success of India's Chandrayaan-3 moon landing, the utilization of Earth's moon as a viable location for landing, living, and exploration is gaining momentum. It is important for startups to consider the challenges of traveling to and mining asteroids in space, but the moon will also be a significant source for powering space activities and for supporting future moon missions. Oxygen, water, and metals can potentially be mined from the surface of the moon and used in supporting ways, such as producing rocket fuel, enabling life-support systems, and constructing infrastructure on the moon and in space.

The moon is known to contain abundant amounts of helium-3, which is a rare isotope on Earth that can be used in the process of nuclear fusion. The current price for helium-3 is $140 million for 220 pounds, and the moon is estimated to have enough of it to generate $1.543 quadrillion. Asteroids, on the other hand, contain numerous metals including nickel, cobalt, and more valuable metals, such as gold, platinum, and rhodium. The asteroid 16 Psyche has been reported to contain $700 quintillion worth of gold.

SPACE INFRASTRUCTURE

1ST YEAR ON THE LIST

TELECOMS

WHAT IT IS

A considerable portion of the world's population shares information through mobile phones, PCs, and various electronic communication devices. While Earth-based networks have primarily facilitated this connectivity, a constellation of space-based satellites and technology will increasingly address the need while impacting new industries.

HOW IT WORKS

In 2023, AST SpaceMobile collaborated with AT&T on the first satellite-to-smartphone call over a 2G to 5G network. Verizon, T-Mobile, and others are pursuing space connectivity too. NASA achieved record 200 gigabit per second data rates from an experimental satellite using laser communications. Meanwhile, Starlink extended its customer lead, exceeding 1.5 million subscribers. In addition to this achievement, Starlink laser-based communications will be tested in space by the private Polaris Dawn mission, which will result in valuable data for future space communications systems. This year opened with John Deere teaming with SpaceX to enhance rural broadband access. An anticipated Starlink IPO could intensify investment enthusiasm.

Competitors have struggled to match SpaceX's breakaway pace. Yet, competitors like Amazon and European-based OneWeb are slowly making progress. Amazon's Project Kuiper aims to deploy a constellation of 3,236 satellites to achieve global connectivity. However, it will take several years before a sufficient number of satellites are in orbit to provide consistent and reliable commercial service. For now, Starlink's foremost rival in terms of broadband capacity is OneWeb, recently acquired by Eutelsat. Rather than direct consumer sales, OneWeb employs a business-to-business model. It sells to intermediaries, like partner Airbus, which then provide access to institutional clients, prioritizing governments and militaries in initial efforts.

WHY IT MATTERS

On Earth, space-based telecommunications are already enhancing cellular connectivity more globally: Both developed nations and developing nations, as well as urban and rural communities, can benefit from this technology, ultimately bridging the connectivity gap that currently divides cultures and populations. Additionally, other innovations in this constellation of technology will improve space science instruments. The use of new technologies such as laser communications will enable more efficient data transmission and could make both communication in space and communication from Earth to space more reliable and efficient. Additional benefits include reduced system weight, heightened security, and greater flexibility for ground-based infrastructure. Taken together, these advantages will enhance the capabilities of scientific instruments and expand the possibilities for data analysis and data transfer. Eventually, laser communications will allow increased volumes of data to be transmitted over longer distances, which will be pivotal for establishing our presence in our solar system beyond our home planet. Ultimately, space telecommunications will impact life in space but also our experiences here on Earth, whether through more efficient communications or enhanced processes to industries such as agriculture.

MAINTENANCE MISSIONS: SATELLITE SERVICING

WHAT IT IS

On-orbit servicing extends the operational life of satellites by repairing, upgrading, or performing maintenance while they are in Earth's orbit. The service can be done through orbit adjustments, refueling, or upgrading instruments.

HOW IT WORKS

The European Space Agency and European industry are working together to develop in-orbit servicing (IOS) technology. Companies working toward extending the life of satellites include Astroscale, ClearSpace, D-Orbit, and Telespazio; they're making progress on IOS concepts involving maintenance, orbit adjustment, refueling, and instrument upgrades. Starfish Space, a startup founded by veterans of Blue Origin, obtained $14 million in funding to launch its own satellite-serving endeavors. After creating a prototype vehicle called Otter Pup, they will attempt to dock on another satellite in orbit before trying it with a full-size Otter spacecraft. Northrop Grumman's SpaceLogistics sold its third Mission Extension Pod (MEP), a propulsion system designed to extend the lifespan of legacy satellites in geosynchronous Earth orbit. The MEP will be placed on a satellite by a Mission Robotic Vehicle using robotic arms, and will essentially function as a jetpack for satellites. This will extend the satellite life by at least six years. The US Space Force now sees the value in servicing preexisting satellites and is investing in early-stage technologies. It's working on a strategy for refueling and servicing satellites in geostationary orbit, and hopes to have the capability by the early 2030s.

WHY IT MATTERS

According to MarketsandMarkets, the on-orbit satellites servicing market is expected to grow significantly, from $2.4 billion in 2023 to $5.1 billion by 2030 with a compound annual growth rate of 11.5%. The telecommunications industry has serious interest in life extension services for maintaining satellites' orbit and reducing fuel costs. Organizations are now viewing satellite servicing as a strategic advantage. By essentially refueling and repairing satellites in orbit, satellite operators will have increased flexibility in response to threats.

Satellite servicing is important for a multitude of other reasons. We rely on satellites for weather forecasting, communications, navigation, and scientific research. Maintaining consistent operation of these constellations will ultimately lead to longer service lives of spacecraft and increase the return on investment for companies that launch these satellites. Servicing will also minimize the risk of space debris as satellites can be repurposed rather than merely decommissioned.

1ST YEAR ON THE LIST

MONITORING EARTH

WHAT IT IS

The harshest critics of space exploration often emphasize the need to focus on the challenges here on Earth before extending our energy to explore the cosmos. As it is, a constellation of satellites and associated space technology have been providing valuable information about our world since the 1960s.

HOW IT WORKS

Much of the infrastructure we've set up in space is for monitoring Earth. Monitoring technology can be used to drive weather-tracking abilities, sustainability measures, and disaster preparedness. As a pillar of space-based research, the International Space Station has a series of platforms for monitoring climate change, including external instruments measuring ground temperature, imaging spectrometers tracking dust particles' impact on climate, and an instrument that measures atmospheric particles from events like volcanic eruptions. Additionally, CubeSats are used by the ISS to observe particle-cloud interactions and meteorological disasters. The European Space Agency also uses a fleet of satellites to monitor soil moisture, measure polar ice thickness, and conduct analysis from radar imagery. Future missions including Flex will map vegetation, and Biomass will gather information on forests. The Canadian Space Agency and Spire Global will undertake their WildFireSat mission using space-based thermal intelligence to support wildfire management. In May 2023, Rocket Lab successfully completed two launches for NASA's Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS) mission. TROPICS will use four CubeSats to monitor the evolution of tropical storms and hurricanes to enhance storm prediction. Furthermore, the escalating regulatory focus on climate disclosure, marked by California's 2023 enactment of mandatory emissions disclosure rules, is further catalyzing the growth of the Earth observation market. Expect the regulatory moment to incentivize the development and technology that facilitate accurate and independent metrics for monitoring our planet.

WHY IT MATTERS

As is the case with all technology, in time, monitoring technology has become more sophisticated since NASA started using it more than 60 years ago and can address a broader range of applications. By establishing a constellation of satellites in space, we can make more observations about a broad swath of phenomena that would require an exorbitant amount of ground-based observers to operate with similar accuracy. Earth observation satellites can assist in tracking gradual environmental shifts including deforestation, rising sea levels, and increasing wildfires. This data can assist in predicting crop yields as weather patterns become more erratic, helping to ward off food insecurities. Governments can use data collected from these satellites to improve their disaster preparedness in the event of intensifying storms, including policies for evacuation plans, resource allocation, and emergency response strategies. Businesses can also benefit by using such data to safeguard supply chains and add resiliency to their value chains. The broader implication is that space exploration and its associated technology offer benefits that go beyond space itself. These practical applications impact our lives today and will help prepare for uncertain futures on Earth.

SELF-ASSEMBLY TECH

WHAT IT IS

Self-assembly technology confronts numerous engineering hurdles related to deploying structures in space and constructing them there. It will unlock new pathways for pioneering novel, streamlined, and versatile space architectures.

HOW IT WORKS

Several groups are experimenting with confronting the challenge of space construction. The MIT Space Exploration Initiative's TESSERAE is the preeminent example of using self-assembly technology to construct space structures: Ariel Ekblaw's project uses flatpack structures and self-assembling tiles embedded with electromagnets to snap components into water- and weather-tight structures that can serve humans in space as well as on Earth. TESSERAE tiles were included on Axiom's Ax-1 research mission in 2022 and further tested during the 2023 Horizon zero-gravity flight by the Aurelia Institute. New features of the tiles include autonomous self-assembly through algorithmic design and enhanced bonding reconfigurability. The MIT Space Exploration Initiative is also exploring magnetically programming cubes to stochastically self-assemble. These ElectroVoxels could serve a variety of applications, ultimately providing solutions for space exploration's unknown challenges. Caltech researchers have also implemented self-assembly principles in a solar power demonstrator that successfully beamed detectable levels of power down to Earth. The design uses modules that are 35 cubic feet before launch but unfurl into huge flat squares 50 meters per side after launch. Space Forge is turning to origami to design Pridwen, its deployable heat shield. The shield creates ample surface area for even heat distribution and can be reused on multiple launches.

WHY IT MATTERS

Traditionally, structures in space have been completely utilitarian in their design. When scientists built the International Space Station, they had to launch disparate pieces into space that were assembled by spacewalking astronauts and robotics. Even as sending payloads to space becomes more affordable, this more archaic process for establishing structures in space is still cost prohibitive, complex, and time-consuming. Other challenges include fitting all composite parts within the confines of rockets and ensuring they withstand the harshness of the launch, while addressing the unforgiving conditions for the astronauts assembling the structures. Shifting the paradigm to self-assembling technology will provide solutions for many, if not all, of these challenges. It will enable more cost-effective solutions and architecture that is dynamic and multipurpose, imbuing structures with new vitality and cultural significance. If Ekblaw's visions come to fruition, space will be fitted with stunning and inspiring cathedrals and concert halls, and not just sterile, single purpose research structures. Dynamic structures have other positive implications, such as the possible ability to self-regulate and self-heal. This technology could also have relevance on Earth, by providing dynamic habitats that can adapt to extreme weather and disaster events in real time.

1ST YEAR ON THE LIST

GREEN PROPULSION

WHAT IT IS

Eco-friendly, storable high-performance hypergolic propellants have been the holy grail of space propulsion for decades, but current breakthroughs are making this elusive form of propulsion more of a reality. Green propulsion alternatives will be key for reducing carcinogenic and environmentally damaging propellants.

HOW IT WORKS

Łukasiewicz Research Networks' Institute of Aviation has made significant advancements in the development of green, high-performance, hypergolic propellants. Its new propellant uses hydrogen peroxide as an oxidizer with a novel fuel, offering high performance, hypergolic ignition capability, and simplicity in engine design, potentially reducing costs for satellite platforms, landers, and launch vehicle upper stages. Benchmark Space Systems is another company dedicated to developing green, nontoxic propulsion systems and technologies to support space missions. According to Benchmark, its Halcyon Avant green bipropellant system boasts a 25% increase in fuel efficiency over other green monopropellants. The Space Enabled research group at MIT is exploring the use of wax-based hybrid rocket propellants, such as paraffin and beeswax. These materials potentially offer high performance, cost-effectiveness, and safety advantages compared to traditional toxic propellants like hydrazine. In an entirely different approach, California-based SpinLaunch is working to develop an innovative space launch system powered by kinetic energy. This technology involves a vacuum-sealed centrifuge mechanism that accelerates a rocket to speeds of up to 4,700 mph (7,500 km/h; 2.1 km/s) before releasing it into space. Once released, the rocket's engines are ignited at an altitude of approximately 200,000 feet. Auriga Space offers another novel approach. In 2023, the company unveiled an electromagnetic launch system, akin to a maglev train, using a ground track to magnetically accelerate a vehicle to high altitudes. Like SpinLaunch, once the vehicle reaches a high altitude, it then fires engines for orbital insertion.

WHY IT MATTERS

It comes as no surprise that present-day spacecraft propulsion heavily relies on toxic and cancer-causing hydrazine propellants, presenting unique environmental concerns and associated safety risks. As the number of future space endeavors and applications continues to rise, adopting environmentally friendly space propulsion methods becomes supremely important. A study by the National Oceanic and Atmospheric Administration further highlights the environmental impact of space travel, indicating that global rocket launches (180 in total during 2022) release approximately 1,000 tons of soot into the upper atmosphere per year. Projected increases in rocket launches risk exposing more people in the Northern Hemisphere to increased harmful UV radiation.

Developing more environmentally forgiving propellants or viable alternative propulsion systems will be no easy task but ultimately will be necessary to adopt eco-friendly and nontoxic propellants to replace conventional, hazardous hydrazine-based systems. This change will further be precipitated by shifting regulatory requirements, changing market demands, and also by the technical and economic advantages offered by nontoxic alternatives.

1ST YEAR ON THE LIST

MONITORING ORBITAL DEBRIS

WHAT IT IS

Ongoing tracking and surveillance of defunct human-made objects in Earth's orbit will help prevent collision catastrophes and ensure that space remains accessible to us in the future. Monitoring goals include avoiding collisions of active satellites, understanding debris-generating events, and aiding efforts to mitigate and remedy debris.

HOW IT WORKS

The growing risk posed by orbital debris has highlighted the need for enhanced monitoring as space becomes more congested. For example, SpaceX's Starlink satellites conducted 25,000 collision avoidance maneuvers between December 2022 and May 2023.

US agencies are ramping up efforts to monitor space debris, placing particular emphasis on objects larger than 10 centimeters. But there's also an increasing awareness of the hazards posed by smaller fragments. Traveling at 17,000 mph, debris as small as a penny can wreak havoc on space assets. Recognizing this, the Office of the Director of National Intelligence launched the Space Debris Identification and Tracking (SINTRA) program, specifically aimed at tracking micro space debris. Separately, US Space Command is training AI on its extensive data, aiming to efficiently discern and prioritize critical threats. In October 2023, the FCC enforced its first space debris penalty in a settlement with Dish Network, forcing the company to pay a fee of $150,000 for failing to remove the EchoStar-7 satellite.

Several companies have also entered the field. In 2023, Japan granted Astroscale a contract worth up to $80 million for a mission to gather data on an inactive satellite in orbit. This mission involves launching a spacecraft that will initially use ground-based observations for proximity and then switch to onboard sensors for closer engagement. The spacecraft will then carry out detailed examinations of the defunct satellite using its integrated imagers and sensors. Another company, Odin Space, is working to detect orbital debris via a sensor on a newly launched space tug. Another startup, LeoLabs, monitors the trajectories and movements of numerous spacecraft in low Earth orbit.

WHY IT MATTERS

Centimeter- and millimeter-sized fragments in space pose the most significant threats to missions in low Earth orbit. Yet, less than 1% of these potentially catastrophic objects are currently monitored, and many are inadequately assessed for the risks they present. The persistence of these debris is alarming; without atmospheric drag, they can remain in orbit for centuries. This means any object sent to space without a plan for deorbit is destined to become hazardous debris. The financial and safety implications of space debris are also profound. In March 2023, an approaching piece of space junk threatened the International Space Station, forcing a hasty maneuver of the $150 billion station to safety. Such maneuvers are costly, averaging $1 million in expenses for propellant and operational adjustments.

Fortunately, we are getting much better at monitoring. Enhanced tracking and cataloging have granted satellite operators the capability to adeptly dodge potential collisions, thereby averting substantial collision risks. Consistent monitoring ensures that essential orbital pathways remain navigable, preserving them for future space ventures rather than rendering them too perilous to explore due to collision threats.

1ST YEAR ON THE LIST

DEORBITING DEBRIS

WHAT IT IS

Simply monitoring orbital debris is not enough—we also need to come up with technology to deorbit existing debris and make plans and protocols for deorbiting future space assets. Deorbiting existing debris is difficult and most efforts today are early stage and experimental.

HOW IT WORKS

Proposed deorbiting solutions include controlled deorbit using spacecraft propulsion; drag augmentation with deployable sails or balloons; and active debris removal. The latter includes concepts like on-orbit capture, lasers to evaporate or slow debris, electric propulsion to dispose debris in graveyard orbits, and inflatable braking devices.

The European Space Agency recently succeeded in guiding a defunct satellite back to Earth, marking the first assisted reentry of its kind. Through complex maneuvers, the agency lowered the satellite's orbit from 320 kilometers to 120 kilometers to ensure atmospheric reentry and burn up. Several startups are also pioneering deorbit efforts: Astroscale's ELSA-M system will be the first to provide multi-removal services, supporting satellite operators including constellations with a compatible magnetic capture mechanism. ClearSpace, another startup, recently secured a contract for ClearSpace-1, the first active debris removal mission to capture and deorbit an object of more than 100 kilograms. Unlike these reactive approaches, D-Orbit's approach is preventive. Its preinstalled Decommissioning Device is externally mounted on satellites before launch. The device will be used for end-of-life maneuvers—once a satellite is no longer functioning, D-Orbit's device will boost the object to burn up in Earth's atmosphere, or into a safer orbit.

WHY IT MATTERS

The escalating issue of space debris isn't just a technical hurdle; it's also an economic opportunity. Introducing financial incentives for space debris cleanup could expedite the process, mitigating the risk of a Kessler Syndrome—a domino effect of collisions that exponentially increase debris. Monetizing orbital debris and space preservation can yield significant savings, with break-even analysis indicating approximately $20 billion saved annually. These costs will soon equalize and then decrease, especially when post-mission disposal practices achieve a 90% success rate, coupled with at least five active debris removals yearly. With forecasts suggesting the space debris monitoring and removal sector could grow from $942.3 million in 2022 to $1.5 billion by 2029, the financial potential is clear.

From a broader economic perspective, clearing space debris effectively unlocks invaluable orbital "real estate." As the space industry burgeons, every cleared orbit paves the way for new satellite deployments, promoting a surge in space-related economic activities and opportunities.

But there are implications beyond the financial. The problem of space debris threatens our deeply human desire to explore and expand. The Kessler Syndrome warns of a bleak scenario where a dense debris field in low Earth orbit instigates a cascade of collisions, rendering space missions perilous or even unfeasible. In such a scenario, Earth could become an unintentional prison, cutting off our access to the cosmos.

COMMERCIALIZATION OF SPACE

2ND YEAR ON THE LIST

OFF-PLANET TOURISM: GETTING TO SPACE

WHAT IT IS

In existence since the 1990s, the commercial space transportation industry initially focused on launching satellites and sending cargo to the International Space Station. Now it's sending tourists on suborbital trips in space.

HOW IT WORKS

In the year between Jeff Bezos' successful first suborbital space tourism flight aboard the New Shepard in July 2021, his Blue Origin took a total of six crewed flights aboard the launch vehicle. In total, it launched 25 nonprofessionals on suborbital flights to the edge of space—a list that includes notable individuals such as actor William Shatner, aviation pioneer Wally Funk, and TV personality Michael Strahan. More recently, Richard Branson's Virgin Galactic completed its first commercial flight, taking its crew to the edge of space aboard the VSS Unity. Members of the flight included two Italian air force officers and an aerospace engineer from the National Research Council of Italy. The flight, called Galactic 01, took the individuals 50 miles above New Mexico and lasted roughly 75 minutes. The succeeding flight, Galactic 02, included Olympian Jon Goodwin along with Keisha Schahaff and Anastatia Mayers, the first mother-daughter duo to fly to space. Startups Space Perspective and World View have a different approach for sending tourists to the stratosphere, namely by balloon. Space Perspective's Spaceship Neptune, equipped with a lounge, bar, and Wi-Fi service, will travel at 12 mph, carrying passengers on sightseeing tours 19 miles above the Earth. World View's balloon-based system will last about six to eight hours and take passengers to an altitude of at least 100,000 feet, allowing the passengers to see the curvature of the Earth.

WHY IT MATTERS

With the tragedy of the Titan submersible, individuals understandably began to compare ocean exploration to that of space. There are similarities and differences between the two. George Nield, who was aboard the New Shepard on March 31, 2022, highlighted those similarities, indicating that both take place in harsh and unforgiving environments, involve a significant level of risk, are only available to a few select individuals, and cost an exorbitantly high amount of money. With these comparisons in mind, Nield admonishes that the space tourism industry needs to update the regulatory framework for commercial human space flight rather than merely rely on informed consent for travelers. He also urges that now is the appropriate time to question whether the industry is ready for a similar tragedy, emphasizing that rushed regulations in this space are essentially bad regulations. These are especially important considerations as a study from the Pew Research Center indicates that while over half of Americans expect space tourism to be commonplace by the year 2073, 65% said they would not be willing to go to space even if given the opportunity. While taking flights to space has its critics, the industry is still valued at $450 billion. Despite the risks involved, affluent thrill seekers will continue to seek novel experiences, such as space flight, instilling continued confidence in the market.

OFF-PLANET TOURISM: STAYING IN SPACE

WHAT IT IS

Staying in space involves constructing and inhabiting innovative structures that can serve tourists as well as businesses and scientists. Private space stations of the future will function as luxury hotels, business parks, and research centers.

HOW IT WORKS

Despite its rebrand, Above Space (formerly Orbital Assembly) still has plans for its private Pioneer Station, described as the first business park in space with gravity, and is taking reservations for its future all-inclusive luxury space hotel. The station, which will be situated in low Earth orbit, is intended to be used by businesses, scientists, and tourists. Pioneer will include a rotating structure to simulate gravity, unlike other space stations. In 2022, Hilton and Voyager Space announced their collaboration to provide a hotel in low Earth orbit. Voyager Space has more recently announced a partnership with Airbus to develop, build, and operate Starlab, the station that will house Hilton's hotel and could one day replace the International Space Station. California-based Orion Span has its own plans for a luxury space hotel known as the Aurora Space Station, with the hopes of offering extended stays in space. If things go according to plan, paying customers will be taken 200 miles above the Earth's surface and spend 12 days at the hotel. Houston-based Axiom Space won NASA's contract to construct the first commercially manufactured module for the ISS. It plans to attach this module in 2026, a second module in 2027, and a third in 2028. After this, its thermal power module will allow Axiom's space station to detach from the ISS to become a commercial free-flying station.

WHY IT MATTERS

Bringing tourists to space and keeping them there for a period of time is no easy task. It also doesn't come cheaply, and critics will always oppose profligate and excessive spending for tourism. But space tourism also channels luxury spending toward continued and advanced research in the space industry. There is the significant opportunity to increase scientific knowledge under the guise of adventure tourism.

In addition to research, space tourism offers obvious economic benefits. It will require new business ecosystems and supply chains, creating entire new industries and jobs. The US Chamber of Commerce anticipates that the US will need more than 1.5 million workers to drive the new space economy. Space hospitality could serve as the testing ground for long-term space missions and colonizing space, providing us with more insights on the systems required to make space colonization possible, and the effects it will have on larger communities living in space.

Visiting space can have other unexpected benefits as well. When Shatner went to suborbital space, he cited experiencing the overview effect, or the transformational and cognitive and emotional shift in a person's awareness when they visit space. This effect would be conceivably more profound for individuals experiencing extended stays in space. Perhaps increased empathy among the affluent is something that critics of space tourism can get behind.

SPACE ENTERTAINMENT AND EVENTS

WHAT IT IS

As we establish long-term settlements in space, we will need forms of entertainment to inspire and stave off the impending isolation being in space elicits. Our time there will assuredly lead to novel events with new cultural significance.

HOW IT WORKS

While not technically in space, electronic duo The Chainsmokers are set to perform the first concert in the stratosphere. The group plans to perform aboard World View's pressurized space capsule tethered to a stratospheric balloon.

Once humans are spending significant time in space, we'll still want to enjoy the cultural elements we are accustomed to here on Earth. MIT-led project Telemetron Orchestra wants to contribute to ways we can create and experience music in space. The project is working to develop musical instruments that function to their full potential only in zero-gravity environments, raising the possibility of a culturally rich life in space. This could enable less gimmicky concert options that one day take place in the actual boundaries of space.

Anticipating future sporting events, the Institution of Engineering and Technology has created a rulebook for how football—soccer to American audiences—would be played on the surface of the moon. Games would involve five players on each team and consist of four 10 minute quarters with 20 minute breaks to give players a chance to rest and recover. The optimistic plan is for these games to actually start happening by 2035, with players wearing slimmed down Apollo spacesuits equipped with internal cooling systems. In a similar vein, the Space Games Federation has identified prospective above-the-Earth sports, such as float ball, which borrows elements from football, dodgeball, and basketball.

WHY IT MATTERS

Whether space becomes a viable option for extended vacations or for human colonization, it will be imperative to bring cultural elements along. These ventures into space will also create new cultures and new pastimes—and economic opportunities. Here, the introduction of microgravity will be both a burden and a benefit. It will hinder us from living our lives exactly as we are accustomed to, and we won't be engaging in the same activities and sports we enjoy on Earth. However, it will also open up new possibilities for innovative competitions. As business parks and other structures become more commonplace, there will be first-mover opportunities to fully take advantage of the space entertainment and event industry. But in the immediate future, space tourism will likely remain a very small percentage of the overall commercial space economy, underscoring the importance of being the first to establish a market and set up shop. While merely being in space would provide an overwhelming source of entertainment for some, individuals will undoubtedly look for new things to do and new ways to stay entertained as we move toward democratized access to space.

PRIVATE MISSIONS

WHAT IT IS

The inception of space travel and exploration was mostly driven by public or governmental interest. However, as early as the 1980s, private organizations began entering the space economy by conducting launches. Now in the 21st century, a growing number of private companies are entering the space economy in earnest.

HOW IT WORKS

China sent its first civilian astronaut into space in May 2023. Gui Haichao, a payload expert, took off from the Jiuquan Satellite Launch Center in northwest China to take part in a crewed mission to the Tiangong space station. Prior to this, all Chinese astronauts in space have been members of the People's Liberation Army.

Japanese startup Ispace had hopes of becoming the first private mission to land an unmanned lunar module on the surface of the moon but was unsuccessful. Its HAKUTO-R Mission 1 module likely ran out of fuel before landing and crashed into the lunar surface. While not successful in landing on the moon, the mission achieved 8 of its 10 goals and also collected valuable data that will be beneficial for future missions.

Jared Isaacman, the billionaire who funded the Inspiration4 Crew Dragon mission, aims to send additional private missions to space under the Polaris Program. The first mission, Polaris Dawn, will attempt to reach the highest Earth orbit ever flown, targeting 870 miles over the Earth. Additionally, the mission also hopes to include the first extravehicular activity for a commercial mission with a civilian astronaut engaging in a spacewalk outside their craft.

WHY IT MATTERS

Private missions require scrappiness and ingenuity and are likely to result in innovations that can only be driven by privatized ventures. Many technologies that ultimately benefit humans on Earth were also used for space exploration. These spillover effects can have immeasurable impact on our daily lives, as we'll continue to see in future space endeavors.

High-profile private missions have the potential to capture public attention and inspire individuals worldwide. This inspiration can lead to a new generation of the public having an interest in space, highlighting the importance of STEM-based education and influencing more students to study science, engineering, and mathematics.

The privatization of space has already proven to have positive effects. SpaceX's reusable rockets have sustainability implications, but they also have greatly contributed to the reduced costs associated with launching payloads to space, acting as a democratizer of the space industry and providing access to a much broader audience. Many of the initiatives associated with space junk removal are also within the private sector. These efforts of cleaning the skies will be crucial for the continuation of the space economy for both public or private sectors. Unfortunately, the private sector is the primary culprit for much of the existing space junk, which is one main drawback of the practice.

SMALLER COMPANIES IN SPACE

WHAT IT IS

Lower barriers to entry into the space industry as well as years of record-setting private investment have given smaller and fledgling companies a seat at the table in the new space economy. But as private investing becomes stingier, smaller companies must focus on core competencies and quality offerings to succeed over competition with weaker fundamentals.

HOW IT WORKS

A number of companies with specialized offerings are already operating in this sphere. There's Firefly Aerospace, which focuses on developing launch vehicles, in-space vehicles, and services for space transportation. Supported by a $112 million NASA contract to focus on lunar payload delivery, it is planning for its vehicles to serve missions in low Earth orbit and also to the moon. NASA selected Relativity Space to provide launch services in its Venture-Class Acquisition of Dedicated and Rideshare (VADR) missions. It was the first company to 3D print rockets and is now applying artificial intelligence and autonomous robotics to its arsenal as the pioneer factories of the future. The Y Combinator-backed startup EPSILON3 provides solutions for space project management through web-based collaboration tools that focus on streamlining tasks related to spacecraft testing and operations. Its customer base includes Firefly, Inversion Space, Rocket Lab, and Virgin Galactic. Vestigo Aerospace places its emphasis on sustainability through deorbit capabilities for CubeSats, small satellites, and launch vehicle upper stages. Rogue Space Systems Corp. is creating satellite vehicles and subsystems for on-orbit services for satellite operators. Its future fleet of Orbital Robots will perform tasks relating to inspection, maintenance, repair, and transport of satellites.

WHY IT MATTERS

The overall market slowdown has had significant impacts on many industries, and unfortunately, the space industry has not been immune: In 2023, investors showed reduced interest in funding large investing rounds for space technology. Still, this pullback does not indicate the Space 2.0 era is coming to a premature end. Investors are anxious and looking for more sure bets. With this in mind, there remains significant enthusiasm for new and innovative space technologies, especially for launch and propulsion systems, manufacturing, and mining. Investors will still be keen on possible returns and novel possibilities the space industry could offer.

Another bright spot in the future market is various countries' interests in returning to the moon. NASA's Artemis program presents compelling opportunities for startups. The US Space Force's drastically increased budget includes a new office for the sole purpose of creating partnerships with the private sector. While private investment remains conservative, government agencies will continue to keep the space economy going. Chad Anderson, managing partner of Space Capital, even thinks the decline in private investment will bring resiliency to the market, as there will be a shift away from momentum investing and back to a focus on fundamentals.

SCENARIOS

Preparing for Game Day on the Moon

Marta Peguero of Spain's national women's soccer team rose to prominence during the 2031 Women's World Cup and further displayed her talents in 2035, when she won the Golden Gall for best overall player in the tournament. That's when she was automatically chosen to captain one of the teams participating in the first-ever soccer exhibition match to be played on the moon's surface. This exhibition match will function as a pilot to assess the viability of having future matches on the moon, as well as the possibility of having a more permanent staple of matches under the Lunar Professional Soccer Association. This pilot match will provide scientists and research-ers with valuable data on the effects of playing sports in such conditions, affirming their postulations of the dynamics of the moon's reduced gravity on ball movement and overall game play.

But, before any of this can be played out on the moon's surface, Peguero must engage in a strenuous condition-ing regimen to ensure her body is prepared for the harsh conditions of space. This comprehensive regimen in-cludes new pharmaceuticals to prepare both the athlete's muscles and brain for the new conditions of space. It also incorporates strength training, aerobic fitness, and balance and coordination exercises to ensure she can adapt to these lower-gravity environments. In addition to exercises, a series of simulated activities aims to pre-pare Peguero for her experience in space. She will engage in equipment simulation in a neutral buoyancy lab to give her an idea of the movement and activity required to function in the streamlined athletic sports space suits that will be used for the activities. A series of virtual experiences using haptic feedback will give her a sense of how the soccer ball might react on the moon. While the high-fidelity experiences are beneficial, there's still noth-ing like trying it all out in the natural environment, an opportunity Peguero is strongly anticipating.

ORIGINS OF A MULTI-PLANETARY SPECIES

SEARCH FOR FAR-OFF LIFE

WHAT IT IS

Are we lonely or are we *truly* alone? The quest to discover life beyond Earth taps into a profound human yearning. Uncovering even the most rudimentary life-forms on far-off exoplanets suggests that we aren't a solitary exception. In their pursuit, scientists are open to detecting both the elementary and the complex.

HOW IT WORKS

The search for life beyond Earth spans the simple to the advanced. We scour nearby planets for signs of basic biology, while also scanning the cosmos for sophisticated techno-signatures, aiming to discover alien civilizations across the full spectrum of evolution. One way of detecting a planet that hosts intelligent life is by studying what Earth would look like from light-years away. Recently, a team simulated radio leakage from Earth's mobile towers to predict what an alien civilization might detect from nearby stars like Barnard's Star, just six light-years from us. Though they found our current radio emissions would be difficult to detect, more powerful future systems could substantially increase our chances of being heard.

Other efforts are focused on finding Earth-like exoplanets orbiting nearby stars. China plans to launch the Tianlin space telescope in 2035 to seek potentially habitable planets while SETI scientists are devising plans for a listening post on the far side of the moon. Artificial intelligence is enhancing these celestial search capabilities. Through sophisticated machine learning algorithms, researchers are pinpointing exoplanets by sifting through data from protoplanetary disks that envelop nascent stars. The James Webb Space Telescope further amplifies these efforts, offering unparalleled insights into the atmospheres of planets located hundreds of light-years away like WASP-39 b. Intriguingly, this gas giant akin in mass to Saturn revealed an unexpected presence of sulfur dioxide in its atmosphere.

WHY IT MATTERS

Discovering alien life has always been a focal point in science fiction, often portraying a unified humanity in response—earthly wars halted, borders dissolved, and racial tensions diminished. But we don't yet know if that unity would materialize in reality.

The Drake Equation estimates the number of active, extraterrestrial civilizations in the Milky Way galaxy by considering factors like the rate of star formation, the fraction of those stars that have planets, the number of planets that could potentially support life, and several others. Considering the cosmos' vastness—with trillions of stars and billions of Earth-like planets—the high probabilities suggested by the Drake Equation lead to a perplexing question: Why haven't we encountered extraterrestrial life yet?

This problem is called the Fermi Paradox, a contradiction between the high likelihood of extraterrestrial civilizations existing and our lack of contact with such civilizations. One possible explanation for the Fermi Paradox is the concept of the "Great Filter." This hypothetical stage, popularized by economist Robin Hanson of George Mason University, suggests that there is a phase in the development of a civilization that is almost impossible to pass. It could be that civilizations rarely develop intelligent life, or that advanced civilizations tend to self-destruct, or any other myriad of possibilities. This concept implies that civilizations with the potential to communicate or travel interstellar distances are extremely rare or even nonexistent. The Great Filter is just one of many hypotheses attempting to explain the Fermi Paradox. As we gather more exoplanet data, expect more theories to emerge.

1ST YEAR ON THE LIST

THE SEARCH FOR NEARBY LIFE

WHAT IT IS

The search for nearby signs of life encompasses not only currently thriving organisms but also traces of past life and indicators of potential future habitability. This involves investigating planetary bodies within our solar system—Mars, Europa, Enceladus, Ganymede—for signs of ancient life, current microbial activity, or conditions that could eventually support life.

HOW IT WORKS

Researchers have long examined Mars for signs of life. Recent data from NASA's Mars Perseverance rover reveals persuasive evidence of organic material. The evidence suggests a more intricate organic geochemical cycle on Mars than previously thought, indicating the existence of multiple reservoirs of potential organic compounds. Importantly, the study identified signals associated with molecules that suggest water may have been a crucial factor in the variety of organic matter on Mars. This implies that the essential building blocks for life might have existed on Mars for a much longer duration than previously considered.

Farther away, there are efforts to scope out potential life hospitable moons—specifically, Jupiter's moons. In April 2023, the ESA launched the Jupiter Icy Moons Explorer (JUICE) to search for life's building blocks there, though some moons are considered more promising than others due to the presence of liquid water, an energy source, and nutrients. Ganymede, one of Jupiter's moons, is believed to have an ocean, making it a key target for the mission. NASA also plans to launch the Europa Clipper, which will explore Jupiter's Europa moon to determine if Europa's ocean could be a suitable habitat for extraterrestrial life.

In addition to these efforts, NASA's Jet Propulsion Laboratory is developing a robot called EELS (Exobiology Extant Life Surveyor); it's designed to look for signs of life in the ocean beneath the icy crust of Saturn's moon Enceladus by descending narrow vents in the surface that spew geysers. Although still in testing and development, EELS' ability to navigate a wide variety of terrains opens up new possibilities for exploring environments that were previously considered inaccessible, increasing the chances of finding evidence of past or present life in our solar system.

WHY IT MATTERS

In the words of Carl Sagan, "The significance of a finding that there are other beings who share this universe with us would be absolutely phenomenal, it would be an epochal event in human history." Finding evidence of even *past* life would be significant. It would provide clues that we aren't alone in the universe and also shed light on the possibility of life elsewhere, even if it no longer exists. If life can form on other planets and moons in our galaxy, it raises the prospect of life being present in other parts of the universe.

Narrowing down our search to factors that facilitated life on Earth, such as water, oxygen, and energy sources, is a logical approach. However, discovering evidence of past or early life could also offer insights into our own origins. It prompts us to question the fundamental requirements for life. For instance, is liquid water essential for life to exist? Are we limiting our search by focusing only on factors that sustain life on Earth? Could other biomarkers exist that would provide more comprehensive insights? Additionally, understanding the reasons for the extinction of life elsewhere could help us prevent a similar fate on Earth. It is crucial to comprehend the conditions that support life, as eventually, humanity will need to expand beyond Earth. Scoping out the "real estate" of our local galaxy before it becomes a necessity to move beyond Earth is prudent and a good life insurance policy.

1ST YEAR ON THE LIST

MOON, THEN MARS

WHAT IT IS

As astronaut Buzz Aldrin once said, "Mars is there, waiting to be reached." But first, we must return to the moon. A Mars mission requires advances in propulsion, life support, and radiation shielding. NASA will use the moon as a proving ground for Mars missions, and possibly as a future launchpad.

HOW IT WORKS

Under NASA's Artemis program, aimed at establishing a sustainable presence on and around the moon, the agency created a "Moon to Mars" office to synchronize lunar and Martian exploration efforts. The moon will act as a proving ground for technologies and equipment, including human habitats, destined for Mars. Artemis II will mark the program's first crewed test, evaluating deep space exploration, the Space Launch System rocket, and the Orion spacecraft over a 10-day journey with astronauts on board.

Two behemoth rockets, one from NASA and another from SpaceX, have emerged as the focal points of the US' moon return aspirations. The fabrication, funding, and functioning of these two spacecraft epitomize distinctly divergent strategies for leaving Earth's confines. NASA's plan uses tried-and-true hardware with expendable rocket stages, while SpaceX's Starship uses entirely new hardware, is designed for more people and cargo, and features reusable components. Once we have returned to the moon, the next step is to set up Gateway, the first space station in lunar orbit and a collaboration between space agencies in the US, Europe, Canada, and Japan.

These countries aren't the only ones with moon-to-Mars plans. India successfully landed Chandrayaan-3 in August 2023, making it the fourth country to complete a successful soft landing on the lunar surface. In early 2024, Japan became the fifth country to successfully land on the moon. These achievements follow a failed attempt by Russia to pull off the same feat. As for manned flights, NASA expects its astronauts to be back on the surface of the moon as early as 2025. China, hoping to become the second country to land humans on the moon, has plans for its taikonauts to land on the lunar surface around 2030.

WHY IT MATTERS

The moon-to-Mars approach enables us to test and validate systems required for the long journey to Mars, including long-duration spaceflight, surface operations, and supporting infrastructure. A successful return to the moon is a stepping stone toward the monumental goal of landing astronauts on Mars, which is the most Earth-like planet in our solar system and likely the best chance of finding evidence of past or present life beyond Earth. As Stephen Hawking noted, "The human race shouldn't have all its eggs in one basket, or on one planet. Let's hope we can avoid dropping the basket until we have spread the load."

The problem of getting to the moon, and eventually Mars, isn't so much technical as it is economic. For these ambitious ventures to be sustainable, they need to be economically viable, and it's unlikely that we will achieve consistent and successful missions until there's a clear profit motive. The effort also comes with geopolitical implications, especially given the chilly relationship between the US and China. Both nations aim to send people to the lunar surface in the coming years, but they do not generally collaborate on space research and exploration, and have limited communication in orbit and beyond. This lack of communication and transparency could lead to unintended crises, especially since both countries are planning to land missions at the moon's south pole. It is imperative to establish clear communication channels and collaborations to ensure the safety and success of these missions, and ultimately, the survival and advancement of the human race.

SCENARIOS

The Moondust Mariner

By 2050, after a series of successful missions launched from Earth, over 100 humans had established a small but growing settlement on the Red Planet. The feats of engineering and courage were remarkable, but the journeys were neither easy nor cheap—the Earth's gravity makes escaping its grasp expensive. For every launch from Earth, the cost was substantial, around $320.5 million for every 100 metric tons of payload. But recent developments have presented a game-changing alternative: launching from the moon.

The moon has become Earth's pitstop and preparation ground for Mars missions. Engineers, taking advantage of the moon's 1/6th Earth gravity, realized that the energy required to break free from its surface was significantly less. The escape velocity on the moon is only about 2.38 kilometers per second, as opposed to Earth's demanding 11.19 km/s. This translates to massive fuel savings. Moreover, the lack of an atmosphere on the moon eliminates aerodynamic drag, another fuel and cost saver.

But the real game-changer is in-situ resource utilization. Recent lunar expeditions have confirmed vast deposits of water ice, especially at the poles. With the establishment of lunar bases and infrastructure, this ice is now being mined and then split into hydrogen and oxygen—perfect rocket fuel. Launching from the moon can reduce costs to just 25% of what launching from the Earth would be: For the same 100 metric ton payload, the cost is now just $80.1 million. This is a dramatic reduction from the Earth-based price tag. When considering multiple missions over years, the savings will be in the billions.

Now, the Moondust Mariner is ready. Built on the moon using advanced 3D printers, and fueled by lunar resources, it is set to be the first craft to travel from the moon to Mars. The success of the Moondust Mariner will prove a vital point: While Mars might be the future of humanity, the moon is its gateway.

1ST YEAR ON THE LIST

THE SEARCH FOR COSMIC RESOURCES

WHAT IT IS

The quest for cosmic resources encompasses the discovery, identification, and extraction of energy and material resources in outer space. A crucial resource in this pursuit is water, essential not only for human consumption but also as a source of fuel to sustain long-term human presence in space.

HOW IT WORKS

Several countries and space agencies are embarking on missions to find water and other valuable resources in outer space. In 2023, NASA launched the Psyche spacecraft toward the unique, metal-rich asteroid 16 Psyche, believed to be composed of up to 60% iron and nickel. Orbiting between Mars and Jupiter, this asteroid is thought to be the exposed core of a primordial planetesimal. By August 2029, the mission will start investigating this celestial body, offering insights into the early planetary building blocks. Russia's Luna-25 lander aimed to confirm water ice deposits in craters at the lunar south pole, as previously detected by NASA and others. The rover failed to land on the lunar surface, but India's moon rover, which landed shortly after Russia's failed attempt, detected several elements including aluminum, iron, calcium, chromium, titanium, manganese, oxygen, and silicon. NASA's VIPER rover will also soon launch to explore the moon for ice and other resources. This robot, targeting a late 2024 landing, will roam the moon's extreme polar regions for 100 days seeking signs of usable volatiles. VIPER's findings will aid efforts to harness these resources for future human space missions. Farther afield, the United Arab Emirates is exploring the asteroid belt to study water-rich asteroids. This mission aims to visit seven asteroids, tracing the origin and evolution of water in these space rocks. The findings will clarify if asteroids could serve as resource depots for future deep space missions. Even farther into space, the James Webb Space Telescope has detected water vapor around a rocky exoplanet 26 light-years away from Earth. Astronomers are now trying to determine whether that water vapor indicates the presence of an atmosphere around the rocky exoplanet, a finding that could have significant implications for the search for habitable planets. These efforts are part of a broader initiative to understand the availability and distribution of water and other resources in our universe.

WHY IT MATTERS

When Neil Armstrong set foot on the moon in 1969, it was a fleeting visit. Now, our eyes are set on a more permanent stay. However, supporting extended human presence in space requires a robust infrastructure. Hauling all necessary supplies from Earth is a costly endeavor. At present, sending a pound to orbit costs around $10,000. NASA aims to drastically reduce this to just tens of dollars within four decades, and Elon Musk's reusable rockets have already significantly reduced the cost of sending payloads to space. Still, the most economical approach lies in tapping into space's indigenous resources—most importantly, water. Water is essential for sustaining life, but it also has immense potential as a rocket propellant. By decomposing water into its components of hydrogen and oxygen, we can create fuel capable of transforming the moon and potentially other celestial bodies into strategic pit stops for space exploration. Using local resources would reduce reliance on costly fuel launches from Earth's deep gravity well. Rather than launching deep space rockets directly from our planet, we could launch from the moon using lunar-sourced propellant. The moon's lower gravity allows for less propellant to escape the gravitational forces. Ultimately, our pursuit of water and space resources transcends economic or scientific interest; it's about sculpting a sustainable path for humanity's cosmic journey.

1ST YEAR ON THE LIST

UNIVERSE MAPPING

WHAT IT IS

Astrophysicists are working to create a map of the universe that helps us better understand space and time. This effort is dedicated to uncovering the mysteries of our universe's formation, its components including the elusive dark matter, while ultimately enhancing our knowledge of the cosmos.

HOW IT WORKS

Astrophysicists developed the most detailed map to date of the universe's early and middle years using the Atacama Cosmology Telescope. Critically, it shows how light dating back to the Big Bang has been distorted, which appears to affirm the standard model of the universe's development and Einstein's theory of relativity.

While we are substantiating our understanding of one aspect of space, emerging evidence is prompting a reevaluation of other prevailing theories. In its first few months of operation, the James Webb Space Telescope found six galaxies formed within the first 700 million years of the universe that seem to be up to 100 times larger than standard theories predict. This challenges our understanding of the early universe: the mass of the stars in these galaxies exceeds the total mass available in the universe at that time.

The European Space Agency has also developed its own specialized universe cartographer—the Euclid satellite. Launched in July 2023, Euclid will observe how dark matter and dark energy have evolved over time, in an effort to reveal more about their nature and role in our universe. Groundbreaking strides are also being made in gravitational wave detection. The North American Nanohertz Observatory for Gravitational Waves recently detected low-frequency gravitational waves, marking a historic breakthrough after 15 years of searching. This discovery is significant because it opens up a new low-frequency window on the gravitational universe, enabling us to study how galaxies and their central black holes merge and grow over time.

WHY IT MATTERS

The mapping of the universe is of profound importance for several reasons, both scientific and philosophical. First, it challenges existing theories. The discovery of the six galaxies that seem too massive for their age forces scientists to rethink and potentially revise our understanding of the early universe, the formation of galaxies, and the distribution of matter. Second, universe mapping is crucial for understanding dark matter and dark energy, which make up about 95% of the universe. Understanding their properties and behavior will lead to a comprehensive understanding of the universe.

Beyond this, however, mapping the cosmos also has profound philosophical implications. It gives humanity a sense of perspective and scale, both literally and philosophically. The Copernican Revolution, which replaced the geocentric model with a heliocentric one, challenged our fundamental understanding of human significance in the universe and major world religions. Galileo's observations were considered dangerous to the Catholic Church, as the observations undermined its authority. New discoveries could similarly challenge modern fundamental beliefs, and we should be prepared for that.

2ND YEAR ON THE LIST

SPACE HABITATS

WHAT IT IS

The next time we land on the moon, we plan to stay long term. A permanent human presence off-planet requires the construction of space habitats to protect us from the harsh conditions of space. Plans are underway to use local resources.

HOW IT WORKS

As we set our sights on establishing a sustained human presence on the moon and Mars, researchers are exploring various methods to construct habitats using local resources. In 2023, NASA funded multiple projects to help astronauts "live off the land" on the moon. One project plans to use lunar regolith to 3D print structures, landing pads, and roads. Another groundbreaking proposal introduces mycelium—derived from fungus—as a construction material. Mycelium can self-replicate and repair, making extensions and repairs easy. Mycelium also excels as an insulator, fire retardant, and is toxin-free. It even rivals the compression strength of lumber and the flexural strength of reinforced concrete. Separately, Chinese scientists have identified glass fibers in lunar regolith as potential building materials.

Instead of building on the surface, some researchers are looking into underground dwellings on Mars. One team has created robots that can autonomously explore caves and lava tubes as possible habitat sites. Using the planet's natural features could require fewer resources while still providing protection from the harsh climate. Meanwhile, NASA's latest Mars habitat competition crowned a design featuring a massive metal dome enclosing a 3D printer. This design produces hexagonal habitats using Martian-concrete, engineered for durability and radiation safety. Notably, key elements, like the dome and windows, will still need to be transported from Earth.

WHY IT MATTERS

Expanding human presence to the moon and Mars isn't merely about planting flags; it's about ensuring long-term survival in alien environments. The moon experiences dramatic temperature swings, and its thin atmosphere provides no protection from the harmful solar radiation or micrometeorite impacts. Mars, while having a thicker atmosphere than the moon, exposes inhabitants to intense radiation, both from the sun and cosmic rays, and experiences frequent dust storms. Additionally, Mars' atmosphere, composed mainly of carbon dioxide, means habitats not only need to be airtight but also equipped with robust life support systems to provide breathable air.

Building these infrastructures requires a complex supply chain that can stimulate industries both on Earth and, eventually, extraterrestrial environments. The demand for advanced materials and technologies will grow. Companies in radiation shielding, life support systems, or innovative building will tap into this expanding market. These habitats demand specialized tools, opening avenues for precision engineering and robotics. As bases expand, there's a push for self-sufficiency and local resource utilization. This could birth a new space-mining industry. Established habitats might also serve as commercial hubs or research outposts. Private entities might lease space or resources, turning these outposts into economic zones, akin to free trade zones on Earth.

SCENARIOS

The Martens' Month on the Moon

The Martens are thrilled to plan their summer vacation: a month-long stay at the Lunar Resort. After last year's tropical getaway to the Bahamas, they are ready for an out-of-this-world adventure. To plan for the big trip, the family scheduled appointments for the required lunar shots—specialized injections to temporarily activate certain genes to help their bodies adapt to the space environment. One set of genes will boost the body's radiation resistance, providing protection from exposure to cosmic rays and solar flares. Another set of genes will make it easier for the inner ear to acclimate to zero-gravity conditions, minimizing dizziness and motion sickness. The Martens don't mind the quick prick of the injections, knowing the lunar genes will optimize their bodies for exploring the moon. Upon their return, the Martens will schedule a visit to receive shots to turn off the temporarily-activated genes, allowing their bodies to readjust to Earth's gravity and radiation levels.

Keith Martens, the dad, is a major history buff. Keith is especially excited that the resort is situated right next to the historic 1969 moon landing site. This was no coincidence—it's strategically located to attract more tourists. Tourism like this makes a long-term human presence on the moon financially viable. The mom, Sandy, is most looking forward to the resort's lunar obstacle courses, which she hopes will rival her favorite "Tough Mudder" competitions on Earth. The Marten kids are equally excited, dreaming of bouncing across the lunar landscape and stargazing from the surface of another celestial body.

After a month of fun and fascinating science, they will return to Earth with amazing memories. But for now, the genetic modifications they're about to undergo will ensure their health and safety in the harsh extraterrestrial environment.

1ST YEAR ON THE LIST

SIMULATED SPACE ENVIRONMENTS

WHAT IT IS

Simulated space environments are artificially created settings on Earth that replicate the conditions of space, including Mars and the moon. The environments are used for training astronauts and studying possible biological and psychological adaptations to space life. The use of virtual reality and 3D printing has enabled more realistic simulations.

HOW IT WORKS

In June 2023, four scientists embarked on a year-long Mars simulation at the Johnson Space Center in Texas. The 1,700-square-foot, 3D printed habitat will expose the crew to Mars-like conditions, where they will conduct experiments, grow food, exercise, and undergo regular testing to provide insights for future Mars missions. The simulation, called the CHAPEA Mission, will also assess the psychological effects of isolation, resource limitations, and communication delays with Mission Control.

China has also developed a simulated environment for moon and Mars mission preparation. A 40-meter-high microgravity tower in Beijing simulates weightlessness experienced on these celestial bodies, providing a cost-effective solution for experiments without the expense of space travel. Researchers will use a linear motor to move objects vertically, approximating four seconds of weightlessness, a more economical approach than launching experiments into orbit.

Virtual reality is also helping us prepare for lunar and planetary surface exploration missions. MIT's RESOURCE project is testing a VR platform displayed on the Oculus Quest 2, designed for geological analysis in lunar and planetary rover exploration missions. The platform integrates environmental data, including temperature, luminosity, and humidity, along with imagery from a commercial lidar camera and RGB imagery.

WHY IT MATTERS

Simulated environments like the Mars replica at the Johnson Space Center can prepare astronauts for the psychological challenges they will face during extended space missions. The stressful circumstances of spaceflight, including confinement within a small space and the physiological effects of living in microgravity, can significantly impact an astronaut's health. NASA hopes that the CHAPEA mission will provide lessons for future astronauts bound for Mars, such as how to collaborate under pressure and deal with homesickness. Kelly Haston, the mission's biomedical researcher and commander, noted the importance of completing the mission without attrition. Though the crew can leave the simulation, Mars has no exit sign, making it essential to understand and address the psychological challenges in advance. Craig Haney, a University of California, Santa Cruz psychologist who researches solitary confinement, highlighted the importance of studying social isolation as it is a dangerous psychological toxin, with debilitating and sometimes permanent effects emerging in just a couple of weeks.

VR also plays a vital role in preparing for space missions and studying extraterrestrial surfaces. It provides a low-cost, immersive environment for studying not only extraterrestrial surfaces but also remote or environmentally sensitive Earth locations. This approach enables researchers and astronauts to explore and understand various terrains and environments without the need for physical presence in space.

BIOLOGICAL ADAPTATIONS FOR SPACE

WHAT IT IS

Surviving space's harsh conditions requires more than physical structures shielding against radiation and other adversities. To truly thrive, researchers are considering biological engineering, reshaping our microbiome and harnessing gene editing to engineer the ideal astronaut for long-term, deep space exploration.

HOW IT WORKS

Astronauts face significant physical changes in space, with the return to Earth posing even greater challenges. In a landmark twin study involving Scott Kelly, who spent nearly a year in space, and his identical twin, Mark, who stayed on Earth, researchers found temporary changes in telomere length, gene expression, cognitive performance, and eye health. Although most reverted to normal upon Scott's return to Earth, some genes exhibited long-term changes, highlighting the need for further research and countermeasures to mitigate the health risks of extended space travel.

Researchers, such as Dr. Chris Mason from Cornell Weil, are working to enhance the human body's resilience against space radiation by activating DNA repair genes and temporarily modifying gene functions. A key focus of Mason's work involves using CRISPR technology to selectively activate genes necessary for space, thereby altering the plasticity of specific targets without completely modifying the genome. Mason's lab at Cornell has engineered chimeric cells combining human and tardigrade genes, the latter being organisms capable of withstanding the vacuum of space. These hybrid cells can trigger tardigrade genes when exposed to radiation, a breakthrough aimed at bolstering human cell resistance to space radiation. Preliminary results indicated an 80% reduction in DNA damage when subjected to X-rays.

The research underscores a pivotal moment in human history when our evolutionary trajectory is no longer solely dictated by natural selection but can be intentionally directed to prepare us for challenges beyond our planet, potentially unlocking a new era of human existence in space.

WHY IT MATTERS

The journey to becoming a multi-planetary species isn't plan B for a dying Earth—it's a recognition of the inevitable: No matter how diligently we care for our planet, the sun will eventually consume it. Humanity therefore will face a choice: migrate or perish.

To avoid the extinction of our species, we must find and colonize a new habitable planet, potentially in a different solar system. However, our current biological limitations mean that the human body is ill-equipped for the journey. Presently, gene-editing technology is permanent and irreversible, which has far-reaching implications, particularly when it comes to germline gene editing (GGE). The primary ethical challenge with GGE is that genetic changes applied to the germline are inherited by subsequent generations—and there is significant debate about the ethics of modifying future children on Earth to participate in space missions.[1]

This is why researchers are not only identifying genes that could make us better suited for space but also figuring out how to make these changes temporary, minimizing discomfort or long-term consequences when we return to our home planet. Moreover, it may be more pragmatic and cost-effective to adapt ourselves rather than undertake large-scale engineering projects for fortification. For example, instead of engineering our environments to block radiation, perhaps we can program our bodies to resist radiation damage.

1. https://link.springer.com/article/10.1007/s11569-023-00438-1

OFFICIAL INVESTIGATIONS OF UAPS

WHAT IT IS

Government efforts to understand unidentified aerial phenomena (UAP) are gaining momentum. Congressional hearings and the establishment of formal offices represent an initial step toward greater transparency and public disclosure on UAPs and also a first step in destigmatizing UAP reporting.

HOW IT WORKS

In 2022, NASA started studying unexplained sightings called "anomalous phenomena." After reviewing about 800 cases by May 2023, the team found no clear proof of alien activity. However, they said it was impossible to draw firm conclusions due to limited data. Shortly later, three whistleblowers, retired military veterans, testified at a House hearing about the UAPs. They warned that the sightings pose a threat to national security and argued the government has been too secretive about them.

Lawmakers who pushed for the hearing called for the government to be more forthcoming about the unidentified anomalous phenomena. In this spirit, the Pentagon's UFO investigative office launched a website to provide public access to declassified information on reported sightings. Managed by the All-domain Anomaly Resolution Office, this initiative focuses on analyzing what the government labels as unidentified anomalous or aerial phenomena. The Department of Defense describes the website as a central repository for publicly approved UAP photos and videos. It will soon facilitate US government and military personnel in reporting objects that infringe US airspace or demonstrate advanced flight capabilities believed to surpass current human technology.

WHY IT MATTERS

"Two possibilities exist: either we are alone in the universe or we are not. Both are equally terrifying."
— Arthur C. Clarke

For years, discussions around UAPs teetered on the fringes of mainstream discourse, often dismissed as conspiratorial. Now, discussions about UAPs have gained legitimacy via congressional hearings, credible witness testimonies, and the creation of official government offices to investigate them. The growing legitimacy of the UAP discussion is fascinating in and of itself, regardless of what the objects prove to be, because it demonstrates how rapidly a topic can transition from taboo to accepted in the mainstream. The legitimization itself warrants study for what it says about the dynamics of idea propagation and normalization.

The testimonies from retired military personnel point to UAPs being more than just an odd phenomenon—they represent a real national security threat. The unknown nature of these sightings makes it difficult for the military to discern friend from foe, an age-old defense challenge. The materials science behind these crafts surpasses our known capabilities, implying either a tremendous covert leap in human technology or an extraterrestrial source.

As these conversations pivot from tabloid tales to the halls of government, the necessity for transparency becomes paramount. The Pentagon's steps to declassify and centralize UAP information signal progress, but the journey to understanding this profound enigma has just begun.

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HOSPITALITY · RESTAURANTS

Future Today Institute

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TOP HEADLINES

Major hotel brands are expanding globally with over 2 billion people expected to travel yearly by 2026. Restaurants are diversifying offerings by exploring autonomous vending and flexible delivery.

01 **Continued Global Expansions**

Brands from Hilton to Club Med to IHG to Four Seasons are expanding to new global markets like Thailand, Mexico, South Africa, and Southern Europe.

02 **2 Billion Travelers by 2026**

According to research by Amadeus, there will be almost 2 billion people traveling at least once a year over the next three years.

03 **Business Travel Grows**

Business travel is three times higher than in 2021, signaling a return to pre-pandemic levels.

04 **Roark Capital Acquires Subway**

The largest restaurant acquisition in 2023, as reported, was the planned acquisition of Subway by Roark Capital, with a purchase price over $9 billion.

05 **Multi-hyphenate Retail Restaurants**

Eighty-eight percent of restaurants plan to offer new products and services that differ from traditional food offerings to differentiate their business and build better client retention.

STATE OF PLAY

Digitized hyper-personalization with contactless experiences is driving frictionless engagements and customer satisfaction.

The hospitality industry continues to struggle with labor shortages, new delivery methods and modes now expected by consumers, supply chain shortages, and increased costs. However, this has not deterred growth for major hotel brands and established quick-service restaurants, with growth for the latter projected to be just under $20 billion in 2023. Many brands and operators are using a balanced approach when applying emerging technologies to address their challenges. While restaurants have been quicker to recover workers than hotels, both portions of the hospitality industry find themselves looking to automate and create contactless and frictionless experiences that ease staffing burdens. In 2023, the industry is exploring virtual experiences, digital concierges, and robotic staff. What was once a novelty is becoming more normalized, as many studies report that guests and customers prefer to interact less with humans and are more willing to share their data for perks. Some of the move away from human services is due to continued concerns over public safety, health, and sanitization. Increases in personalization are also helping transform expectations for this industry, so both restaurants and hotels are trying to learn as much as possible about guests and diners to anticipate their needs. In some instances, researchers are exploring how technology can turn such a capability into a mostly back-of-house process, where everything from room selection to the food delivered is pre-prepared based on what is known about a guest's preferences.

STATE OF PLAY

Loyalty and rewards programs have renewed interest in on-site experiences, and companies are shifting toward exchanging location verification for increased access to amenities and secret menus. With customers sharing more information about themselves, the demand for secure data privacy is rising. For customers, the collection process remains highly contentious, with their decisions on whether to share data highly influenced by what information companies are willing to share about themselves. Recognition-based technology, such as mid-air haptic and facial recognition technology, has increased in both sectors, with many guests accepting it because it enables more self-service transactions. As Gen Zers continue to flex their spending power, they expect companies to provide transparency on their actions and commitment toward bettering the planet, the workforce, and general equity. The global shift toward delivery and takeout has led restaurants to revamp their spaces for efficiency, exemplified by the UK's Pret A Manger, which expanded its "Dinners by Pret" delivery service and redesigned select shops to accommodate the surge in off-premises dining demand. As we look ahead, understanding and embracing these trends will be pivotal for both restaurants and hotels striving to meet the evolving needs of travelers and diners in this transformative era.

KEY EVENTS

MARCH 15, 2023

China reopens to foreign tourists
As one of the last major countries to re-open its borders to foreign tourists post-pandemic, China lifts its restrictions and begins issuing travel visas.

MAY 22, 2023

Wendy's instant pickup
Wendy's begins testing a new delivery method using robots and underground tunnels to deliver food to its parking lots.

SEPTEMBER, 2023

Expanding focus in India and Southeast Asia
Global occupancy levels for hotels are up with revenue per available room up 17%. Occupancy rates in locations like Bali, Jakarta, and Seoul are seeing higher occupancy than 2022.

MAY 8, 2023

Biometric access changes
Salito, known in the hospitality industry for electronic locks, acquires a UK-based company innovating in facial recognition technology.

JUNE 26, 2023

Autonomous QSRs
Sweetgreen announces it expects all of its restaurants to be automated in the next five years.

SEPTEMBER 7, 2023

Electrification parking
Hilton's expansion of Tesla charging stations will make it the largest provider of EV charging stations in the industry.

LIKELY NEAR TERM DEVELOPMENTS

POTENTIAL DISRUPTIONS CONTINUE TO LOOM

While many customers need stability to know if they should move forward with taking a trip, stability is not assured, which is normal. However, new tensions are arising that could further disrupt the market and industry. Much of these disruptions are due to customers demanding more personalization, which creates more work for businesses. That's especially difficult when these new technologies are increasingly vital to remain competitive, but the labor force lacks the skills needed to implement them. These shifts to the market also offer opportunities to increase services and provide new touch points.

Labor Tensions

As technology adoption increases, service unions could begin to feel pressure to block developments they feel would replace their members. Examples include the outcome of the recent SAG-AFTRA strike.

AI Avatars

Brand representatives can curate their interactions based on a consumer's preferences and response to targeted media. Booking interactions will be more friendly as a result, and dining experiences feel more personal. These nuanced relationships will transcend short-term brand mascots.

Delivery Everywhere

Convenience will continue to win out. Delivery has returned to pre-pandemic levels, but now consumers expect to be able to get items not just at home but wherever they are at any given time. This will require new tracking methods and omnichannel delivery methods.

Power Stability

With climate change continuing to disrupt energy infrastructure, hotels and restaurants will need to prioritize improvements to remain stable for customers. This will be a challenge as the construction industry is also dealing with a labor shortage.

Dark Dining

As space becomes a premium, store footprints will continue to shrink, creating fewer positions for human workers and more for robots. This can increase market presence, but will require greater upfront investments and market research.

Technology Upskilling

Current hospitality education institutions may need to add courses on technology and how to use it within the industry. QSRs will face challenges if they depend on employees lacking technological skills, necessitating upskilling cycles to train them to use new in-store technology.

11 MACRO SOURCES OF DISRUPTION

Technology	Media & Telecom	Demographics	Environment	Government	Public Health	Education	Geopolitics	Infrastructure	Economy	Wealth Distribution

WHY HOSPITALITY & RESTAURANT TRENDS MATTER TO YOUR ORGANIZATION

Tech-Enabled Personalization

Customer segmentation is time-consuming, costly, and often overwhelmingly generalizes consumers. Hotels' and restaurants' use of tech-enabled personalization and new product offerings could disrupt other markets that have yet to find ways to curate customized offerings.

Interactive AI

Traditional marketing will slowly shift as customer loyalty becomes more attuned to interactive AI offerings by restaurant and hotel brands. It will also offer new types of cross-industry partnerships, as these AI offerings will be able to cross-promote for hotels, travel destinations, dining locations, and events.

Nomadic Living

As many populations around the world embrace WFH, they are also becoming more mobile. This nomadic way of living will lead to lodging revenue growth for companies that can attract more mobile workers while differentiating themselves from their competitors.

Smart Management

Adoption of smart management systems will continue to become a competitive advantage for those that make the leap first. These systems will allow hotels and restaurants to redefine customers' expectations. They will also help businesses be ready for future energy and environmental regulations that will disrupt operations.

Pre-Experiencing

This trend will redefine the customer journey, enabling new selection criteria and opportunities for engagement. It can also provide new insights into consumer behaviors, based on what they interact with and what upselling options are available, and create new product offerings that generate revenue even before a consumer comes to the physical location.

Verified Loyalty

New forms of loyalty programs that include verification can improve transparency and customer retention. They can also offer ways to cross-promote new offerings and test new marketing strategies, and can potentially collect more data to further amplify the personalization customers are requiring.

OPPORTUNITIES & THREATS

Threats

Automation could create curated guest and customer experiences, reducing the time needed to perform tasks. It would require a heavy lift of data on the front-end and permissions from customers, but this could become an attractive selling point that continues to grow as customers interact with the automation platform.

Chatbots becoming virtual avatars would allow for more friendly customer exchanges, especially as avatars become more lifelike. Companies with traditional call centers could replicate face-to-face interactions with this technology.

Virtual try-before-you-buy add-on purchases could increase upfront profit and generate new revenue streams for multi-hyphenate businesses. The same technology can support product development and trials to gauge consumer interest.

Digital means could let companies offer increased wellness offerings, both in the home and on site. Their entry into new markets would require relatively little investment compared to developing a full site location.

Transparency through verified loyalty programs can increase trust for customers and businesses. Customers would be confident that their rewards are accurate and secure, while the business gets a platform for sharing their latest transparency reports.

Opportunities

Businesses not already addressing the lack of data consistency and the need to verify existing data and implement new data collection tools are lagging. Data will continue to become more vital and ubiquitous.

Both businesses and workers face uncertainty in the future of human talent. Companies need to understand their weaknesses in future talent and provide messaging to current and potential employees to minimize fear of future job loss.

Delivery everywhere makes it harder to manage customer expectations and increases competition as traditional restaurants could see a decrease in foot traffic. It also impacts quality control and relies heavily on third-party platforms.

Guests' expectations for medical biome testing could lead to on-site wellness facilities needing to follow new medical guidelines and procedures that increase staffing needs and change spatial allocation and design. Their liability risk could rise as a result.

Fast dining could take over slower traditional dining as consumers become increasingly time-poor. The importance of physical place could subsequently decline, meaning current investments may need to be rethought and redeveloped. Smaller urban infill locations may become a desirable strategy.

INVESTMENTS AND ACTIONS TO CONSIDER

1

Consider investing in data collection and analyzation partnerships if these tasks are not already being done in-house. You'll gain the level of granular customer insights needed for making informed decisions about the future. It will also increase efficiency by predicting staffing changes will need to be made.

2

Upskill your talent now for a technology coworker or director, and consider looking for on-site technicians who can service new enabled equipment. Also important will be creating partnerships with or hiring companies that can implement these technologies. Evaluating them now will prepare you for investing in them when the time is right.

3

Consider transforming loyalty programs into data collection tools as one way to obtain data from your customers. This can also begin to set future payment expectations as blockchain technology scales in the future, and will be seen as a step in data security and privacy by consumers.

4

Start investigating the adoption of robotic equipment while talent shortages persist so you can leapfrog competitors that have already invested and installed their machinery. Focusing on where staffing shortages could occur— versus investing in every flashy device—will allow you to bolster your production line.

5

Since reliable delivery staff will become quintessential to the market, especially as delivery becomes ubiquitous, look for the right third party that has verified the skills of their delivery staff. For those third-party vendors, consider finding ways to partner your employees with the right food vendor.

6

Prioritize site development for dark stores and infill locations so that if there is a talent drought, your stores do not go dark in other ways. Automation can help create smaller footprints, which means new site considerations could be developed for target markets. This includes hotel brands wanting to create mini experiences to attract visitors.

CENTRAL THEMES

Getting Personalization Right

Guests expect experiences to be customized to their granular needs and wants. Combine this with the fact that companies in the hospitality industry, whether they are willing to admit it or not, are struggling to figure out how to increase their market share and customer loyalty and retention in unique ways. And companies putting money toward personalization are finding there are more ways than ever to achieve these goals. Personalized tastes, viewing experiences, rooms, food, and even entire menus are all on the proverbial table. Machine learning offers ways for companies to jump-start this process, but lacks tools for either collecting the data or translating the data they have. Food and menus will be the most affected by this increase in personalization, as 3D-printed and engineered foods offer alternatives to traditional meals and flavor profiles. Potentially, multiple diners ordering the same dish from the same menu would have entirely different experiences from one another, with their food reflecting their idea of just the right amount of saltiness and spice.

Elevated Experiences

Dining is no longer just about the sense of taste; increasingly, people are demanding experiences that cater to their other four senses, too. As luxury experiences become more in demand, many are gravitating toward more sensorial experiences to elevate their dining events. New forms of synthetic media, including avatars and digital menus, offer highly entertaining interactive experiences, and immersive rooms create a complete separation from the reality outside. These kinds of experiences enhance the food, and provide guests with a high-level expectation of their future visit to the physical space. They are being used to help combat the pickup or delivery-first mentality for restaurants, while serving as educational tools that resorts and other hotel locations that host events are using to stay competitive. Elevated wellness experiences also are providing guests one-of-a-kind experiences, especially when enhanced by technology. Boutique brands around the world are experimenting with new digital treatments meant to elevate mood and detox the body based on on-site testing.

Labor Automation

Amid persistent labor shortages, many hospitality companies are using technology to automate their staff functions. Use of AI is happening for dynamic pricing, robotic cleaning staff, and automated concierge services. This automation, once regarded as off-putting, is now being seen as a boon to customers and guests. Resource management systems offer ways for operators to hone in on specific staff functions and determine when they should be carried out, as well as when guests will want to interact with actual humans. In the quick-service restaurant industry, automation of the back-of-house cooking functions seem to be steadily increasing with more niche robotic equipment continuing to be developed. While ghost kitchens are declining, this automation may be one way for them to move forward, especially if they use it for the delivery process as several prominent chains have done.

CENTRAL THEMES

Climate Impacts

Climate change continues to impact the hospitality industry. Disclosures for ESG standards are shifting decades-old practices; if companies are transparent in their sustainability actions, they could acquire new customers, but if they lag, they could be canceled. Climate change is a driver behind how spaces are being designed and how they'll function, with a changing reality requiring new energy sources and water reclamation equipment. The electrification of vehicles is also shifting needs for guest, employee, and delivery driver parking. EV adoption will increasingly be an important area to watch and consider. Lastly, food production and waste has become more important, especially with the disruption of supply chains due to extreme weather, which is introducing new practices for watching what goes on the plate and what goes in the bin.

Less Human Contact

Hotel guests are finding more ways to avoid human contact. They are happy to walk into a venue and have a completely automated check-in process, their room controlled by technology, and engage with events and the checkout process without seeing or speaking to a human staff member. This comes as no surprise as technology becomes more pervasive in the home, work, and retail worlds. Guests expect to be able to use technology to adjust their settings and customize their stay. Restaurant goers are moving into this category as well. Ordering can be done more seamlessly at the table with QR codes, and servers are using technology to know their guests' needs and dietary restrictions. This knowledge helps to streamline the overall process, including faster customer service and turnover. Traditional dining restaurants are not following this trend as much, which could create an interesting dichotomy and reveal whether future customers prefer slower or faster service.

Hyper-Locality

Determining where you stay or dine is becoming more localized to niche locations, reflecting a significant shift towards hyper-locality in the hospitality industry. This trend is evident from the emergence of nomadic hotels that tailor their location and offerings based on the precise desires of their guests to the meticulous precision of last-mile delivery services, ensuring meals reach consumers at their exact locations. Hyper-locality is not just about geographical accuracy; it's also about tailoring experiences and products to meet the specific cultural, dietary, and experiential preferences of local markets and individual consumers. Combined with technological advances in avatars and other interactive experiences, those local experiences could also become global marketing tools. This approach will allow restaurants and hotels to offer highly personalized experiences, fostering a deeper connection with their clientele.

ONES TO WATCH

Michael Bickel, CEO at TableMation, for driving tech-driven, immersive dining.

Steven Chen, architect at Moliving, and **Hanna Bem,** COO at Moliving, for designing the first nomadic hotel.

Robin Simsa, CEO at Revo Foods, for enabling 3D-printed salmon at scale.

Dr. Cindy Heo, associate professor at EHL Hospitality Business School, for their paper on the novel use of machine learning for dynamic pricing.

Dr. Luciano Viverit, doctor of philosophy at INFN Milan, and **Luis Nobre Pereira,** vice president of Research Centre at University of Algarve, for their paper on the novel use of machine learning for dynamic pricing.

Dr. Vikas Sadvilkar, CEO at AirOWater, for enabling the development of clean water from humidity in the air.

Graeme McLean, professor of marketing at the University of Strathclyde-Glasgow, and **Dr. Jennifer Brannon Barhorst,** associate professor of marketing at the College of Charleston, for their paper on the role of virtual reality in hotel booking.

Grzegorz Sochacki, Ph.D. student at the University of Cambridge's Department of Engineering, for his work on a robot chef that learns to taste food.

Rajat Suri, former CEO at Presto AI, for software and system development efforts leading to AI-enabled drive-thrus.

Gareth Hughes, founder and CEO at Crave Interactive, for developing interactive tablets that allow guests to utilize AI in hotel rooms.

Ben Kaplan, owner of PLNT Burger, and Ken Sutton, CEO of Yobe, for their work on voice-ordering at kiosks.

Shagufa Ali and **Anupama Singh,** assistant professors at Graphic Era Hill University, for their patent on a method of reviewing and selecting hotels based on real-time hotel rankings.

Chris Silcock, chief commercial officer at Hilton, for working on prebooking experiences.

Ajay Pratap Singh and team, for their patent for IoT-based predictive hotel arrival.

Chris Somogyi, Dr. Soojin Jun and **Paul Levins,** co-founders at EverCase, for their work in the novel use of electric and magnetic fields for food storage.

Logan Kim, CEO at Nuvilab, for using AI to analyze food nutrition and waste.

Marc Handels, chief technology and innovation officer at SALTO Systems, for the company's work on facial recognition technology for the hospitality industry.

IMPORTANT TERMS

Back-of-house (BOH)
The area in a hospitality establishment for food preparation, storage, and staff administration, generally away from customers.

Biometric payments
Technology that uses biometric data like facial recognition, gestures, voice, or fingerprints for identification to complete a transaction.

Dark dining
A restaurant location that is completely autonomous and not meant for dining in.

Digital loyalty programs
Membership or rewards programs that use digital technology like blockchain to track customer interactions and provide membership benefits.

Environmental, social, and corporate governance (ESG)
The framework and disclosure around how a company addresses these issues.

Extended reality (XR)
A technology that can augment the physical world through either virtual or augmented reality.

Facial recognition technology
Technology used to authenticate customers by analyzing their facial features.

Frictionless experiences
Experiences that minimize physical contact, layout obstacles, and seamless interactions for guests and customers.

Front-of-house (FOH)
The area in a hospitality establishment where interactions between guests and staff occur.

Kiosks
Self-service terminals of any kind, typically used for ordering or obtaining information.

Mid-Air haptics
Technology that can track movement and enable the sense of touch without touching a physical object.

Modularly built
A construction technique that uses prefabricated components to create a space, building, or other structure.

Natural language processing (NLP)
AI that can understand the human language and respond in a human-like manner.

Quick-service restaurants (QSR)
Restaurants that prioritize fast and convenient service over longer-stay dine-in experiences.

Revenue per available room (RevPAR)
A key performance metric of the hospitality industry that divides the total room revenue by the number of available rooms and assesses a property's performance.

Smart management
The use of technology to automate certain parts of the operational management of a restaurant or hotel.

ENHANCED HOSPITALITY EXPERIENCES

1ST YEAR ON THE LIST

INTERACTIVE AI

WHAT IT IS

AI is being used as an end-to-end assistant, as well as a synthetic persona to engage with guests. Traditionally relegated to the back end of the experience, this is happening from start to finish.

HOW IT WORKS

AI is becoming more interactive, with many hospitality companies using AI personalities, avatars, or interfaces to interact with guests. While these AI interactions started with chatbots responding to online inquiries, complaints, or reviews, they now occur during booking, while on the hotel's premises, or post-stay. Tools like Akia use NLP to speak to guests in their native language and answer questions, while Quicktext integrates into messaging platforms to interact with potential guests. In April, Breezeway announced the launch of its Assist AI, which helps short-term stay rentals automate responses to potential guests about property information like parking, Wi-Fi logins, and other general information.

A recent patent shows how AI is now moving to the front-end experience for guests as well, through travel agencies that are looking to manage booking blocks of hotel rooms. Crave AI, from Crave Interactive in London, works as a digital interactive display window. Guests use it for learning about and booking rooms and spa treatments, and receive voice, video, and image replies to their queries. At the Cosmopolitan in Las Vegas, the AI bot Rose touts that she can "hook you up" with the best the town has to offer. Rose's informal discussions about her favorite things make it seem like is a Sin City resident.

WHY IT MATTERS

Most guests are starting to prefer less contact with human staff. For companies considering using AI, consistency will be key in implementing this technology, as well as an increased social awareness for how adoption affects public perception. Integrating AI that uses NLP will lead to better customer experiences while reducing time needed to reply to guests. These AI interactions will also provide new data, including detailed segmentation information that a company can use to update guest profiles, map customer journeys, and train staff. It will be important to keep online and onsite experiences consistent, so guests feel that they get to know the AI. New forms of entertainment and recognition will open up to increase loyalty and engagement. Traditional rewards programs can be cumbersome, as with many other processes, but this and other tasks could become how AI manages mundane customer interactions. If used correctly, the technology could also help improve training by modeling the best interactions as rated by guests.

SMART ROOMS

WHAT IT IS

In-room technology now allows for voice-controlled interactions, new VR activities, sleep sensing beds, and more. IoT sensors, control panels, and voice-activated automation are helping to create unique guest experiences.

HOW IT WORKS

Voice assistants for smart hotel rooms are becoming guests' preferred technology advancement, and almost half of them report this technology factors into their decision about where to stay, according to a Hotel Technology News survey. Over half of hotel operators already offer or plan to add voice-controlled technology in their guest rooms. Control through tablets has also become an expectation. Hotels like CitizenM and Four Seasons currently offer in-room tablets that control the blinds, adjust the temperature and lighting, and allow for food ordering and information searching.

Increasingly, hotels are integrating smart sensors into guest rooms for more personalized control, safety, and efficiency. These sensors can be integrated into the HVAC system and occupancy sensors to track the areas being used and adjust building systems accordingly. In Lake Nona, Florida, the Wave Hotel will use Well+tech by Wave for air sanitization and circadian lighting to boost a guest's circadian rhythm. Well+tech is also using AI-enhanced beds to help guests get a better night's sleep. Sensors by pools and bath tubs are being explored in a patent for safety in monitoring water levels and temperature when a person is present.

VR is also making hotel rooms smarter with projection interfaces for guests to interact with and change how the room looks. Marriott's customers can order VR headsets to their room and then have customized virtual experiences. One experience is a VR Postcard, which lets them experience stories from travelers around the world.

WHY IT MATTERS

Guests are beginning to expect smart and enabling technology in the room, and will increasingly feel neglected and frustrated by older technology. As properties look to compete and differentiate themselves, smart rooms offer more engaging stays and experiences while feeding companies new data streams for how their future properties should operate. As the data becomes increasingly important to guests, so should considerations around transparency for how it will be used. Smart rooms can also be curated based on a value of the brand or a location, meaning the smart room could interact with its own style if it were in Mexico versus Italy. While the implementation of this technology can be a costly investment, a return will be realized as guests increasingly rely on it for elevating their stay. Hotels can also craft a safety campaign around these improvements, as they offer more curated control over the systems and tools used to clean rooms. However, cumbersome interactions will need to be smoothed out prior to launch, or the technology will be seen as a burden rather than an exciting offering. This is especially pressing for technologies that will be augmenting traditional human-staffed roles.

DIGITAL WELLNESS TREATMENTS

WHAT IT IS

Virtual wellness experiences, detox technology, and exercise technology are being integrated into traditional spa and wellness centers.

HOW IT WORKS

Physical wellness has been a mainstay of offerings from the hotel industry, and Peloton and other interactive technology exercise equipment have already become integrated into these offerings. Physical and mental wellness experiences are also now becoming more technologically enabled. Sensei Lāna'i, A Four Seasons Resort in Hawaii, is offering wearables and an analysis of a guest's biometric data to optimize health awareness and offerings.

Detox technology is also enabling better physical health, with Montage Laguna Beach offering VR immersive experiences and detox face and feet technology, and the spa at Claridge's offering the UK's only MLX i3Dome, a three-in-one body-detoxifying chamber. Mental health offerings enabled by technology are continuing to grow, too. Well+tech guests will have access to virtual reality-led meditation with LUVRworldwide, and the Carillon Miami Wellness Resort has what it calls the biostation, which is an anti-aging and medical wellness center. One offering at the biostation is a meditation pod that uses color, sound, and energies therapy. Akasha Spa at Café Royal has launched London's first Electronic Music Meditation class, and Kimpton Hotels has partnered with Talkspace to provide free online therapy sessions for guests.

WHY IT MATTERS

Wellness continues to be an important motivation for travel and a major factor in guests' hotel selection criteria. With many still looking to spend down unused monies from the pandemic and prioritize their health and well-being, offering unique digital wellness experiences will garner international attention and guests. Aligning with these preferences ahead of investments will be key to their success, as well as make them more affordable. Digital wellness also offers non-traditional engagement with guests and can be done to scale in multiple sites, meaning smaller sites could still offer high-end digital wellness treatments that take up smaller footprints. More integration of wearables and data will also impact wellness treatments and help companies curate them to meet individual needs. This will require policies and adherence to health information privacy and individual customer expectations. A particular challenge arises—capturing the data during the short amount of time when guests are on the property—so hospitality companies will need to factor in the ability to process data quickly.

SMART RESOURCE MANAGEMENT

WHAT IT IS

The hospitality industry is responding to the call for better use practices by investing in smart resource management platforms, devices, and systems.

HOW IT WORKS

Water is a top-of-mind resource for most hotels, but especially in areas where it's scarce like the Middle East. In Dubai, Delta Hotels by Marriott are employing new technology to address water scarcity in the region. The hotels use India-based AirWater's Atmospheric Water Generators to turn the humidity into clean, drinkable water. In fact, they have two of these machines to provide water to all its guest rooms, restaurants, meeting facilities, spa, and gym. For pools, WaterGuru's SENSE is an AI that can self-manage multiple pools for better water management and testing. And for HVAC, the Beverly Hilton and Waldorf Astoria Beverly Hills are using an ice-based thermal energy storage system called Nostromo Energy to provide carbon-free air conditioning. Singapore-based proptech startup SensorFlow offers IoT and AI integration into a hotel's energy management system to help automate energy consumption. Hotel Marcel in New Haven, Connecticut, has become the first net-zero hotel in the US by relying on a variable-capacity heating and cooling HVAC system and Mitsubishi's first installation of its Heat2O all-electric high-volume hot water system.

WHY IT MATTERS

Many guests are sensitive to the needs of the region they are visiting. They are well aware when there is a drought, and those who are eco-conscious will expect the places they stay to not tax a region's fragile resources. In many regions, government entities are banning pools due to climate change. This, along with strains on existing power grids, will force the hospitality industry to become more responsible with its resources, and will necessitate hotels go beyond simply asking guests to reuse their sheets and towels. With many guests using sustainability to guide their travel destinations, hotels could become rated based on their carbon footprint and sustainability strategies or implementations. This type of information is readily available in other markets—like grocery and dining, thanks to apps that give you information on how much your food is adding to your carbon footprint—but this type of information seems less marketed and offered in the hotel industry. For early adopters, it could be an effective marketing strategy and a differentiator.

NOMADIC AND MODULAR HOTELS

WHAT IT IS

While a nascent trend, some new hotels are creating mobile properties that ebb, flow, and move due to guest demand. Nomadic and modular hotels can be quickly constructed, taken down, and relocated.

HOW IT WORKS

The hotel industry is responding to the market's increased desire for mobility with its own version of a pop-up: movable hotels. Moliving is building a modular and movable hotel in New York that can scale up depending on needed inventory per season. The structure costs $150,000; it takes about five months to manufacture and can be removed without harming the land it sits on. Habitare is creating a movable luxury hotel that is meant to travel to locations that might have been previously inaccessible. Its model creates instant destinations, based on demand, that are quick and affordably constructed.

For more permanent, but still modularly built hotels, we can look to Volumetric Building Cos.: It's working with Fairfield by Marriott to use modular construction to rapidly expand Fairfield's existing properties worldwide with a new prototype. Uni Villas offers modular units to create mini resorts for entrepreneurs. These units are prefabricated and shipped on the back of a truck with furniture and check-in systems included. London's Aylott + Van Tromp offers Hytte: 15 pre-designed cabins for hotel operators to use. The cabins can either be off-the-shelf or customized and can be used for local stays or more remote destinations. Both Uni Villas and Aylott + Van Tromp say these types of creations are essential to enable the hospitality industry to respond to demands for new locations, while being sustainably minded.

WHY IT MATTERS

With a more mobile population looking for curated places to live and work, and the blending of working spaces into the hospitality sector, nomadic and modular hotels could offer more temporary ways to capture those guest stays. This could give the hospitality industry the potential to disrupt apartment and co-living spaces, as well as co-working locations with more nomadic and pop-up locations. While the mobility infrastructure could prove challenging, it could also allow development costs to go much further, allowing companies to set up a bare-minimum site versus a fully new-build location. As urban centers try to find ways to revitalize and reinvent themselves, these modular and nomadic locations could bring new opportunities for tourism and experiences, which means there could be new and specialized location offerings. This, paired with other entertainment offerings like concerts or events that are typically hard to reach or attend due to lack of hotel space, could also increase their relevance to the industry. Studying when market saturations peak will be critical to know where to invest here.

SCENARIOS

Nomad Stays

While traditional hotels are holding strong, there has been some strong competition from an unusual source: RV parks. Once thought of as a destination for campers and mobile families, with the addition of off-grid infrastructure and modular hotels, RV parks have become all the rage for pop-up hotels. Initially, there was an increase in RV parks in Norway, as tourism to its luscious fjords rose. Acting quickly, Marriott spun off a new division called Nomad Stays, which offers predictive insights into when and where pop-up hotels should be built and then taken down and moved to a new location. The Vinjerock and Træna music festivals were the first trial runs in 2028—while they had moderate success, what was especially newsworthy was that the modular cabins were set up for the Træna festival first, taken down, shipped, and set up for the Vinjerock within a week's time. Attendees reported that they much preferred to sleep in one of the modular sleeper bunks that had its own facilities over using a tent. Once news of this got out, Burning Man organizers and participants soon began to contact Nomad Stays to see if they could purchase or rent these cabins, especially when the weather called for rain. Pretty soon, Nomad Stays had set up roving sites around the Isle of Arran in Scotland, Ladakh in India, and even Mount Cook National Park in New Zealand. Nomad Stays' current top demographic? Autonomous vehicle owners. With more autonomous vehicles and people working from home, many have their cars book their Nomad Stay for them, and just let the road lead them to their next destination.

1ST YEAR ON THE LIST

FRICTIONLESS STAYS

WHAT IT IS

Beyond contactless checking in and out, new technology for payments and authentication are minimizing staff-guest interactions and providing guests with greater access to the facilities and activities on site.

HOW IT WORKS

Interactive digital concierges and XR technology are now facilitating a hotel guest's entrance experience. Uniguest offers an all-in-one digital concierge signage system for finding information on restaurants, events, and other information. The goal of the system is to reduce the need for guests' interactions with human staff, thereby freeing up humans to perform other work. At Yotel's Singapore location, digital check-in kiosks similar to the ones used at airports provide guests a frictionless and humanless check-in process. The hotel has also been using robots to help with its service offerings since 2019.

Voice assistants are providing support, as guests can use them to request towels, check in or out, and make reservations without having to call the front desk. A recent patent is exploring using sensors embedded throughout the hotel to predict when guests will arrive, based on their uploaded profile and past activities, so staff can address the needs of the hotel room while guests are away. Some are using wireless sensing technologies to automatically identify and authenticate guests throughout the site, which helps enable seamless transactions. Similarly, contactless payments are no longer reserved for large resorts. Two hotels in Ibiza are using Very Important Bands (VIBs) to allow guests to skip lines, pay, check in and check out. Even elevators are becoming more frictionless with the NZ Technologies HoverTap system, which allows for panel control by a touch-free hand gesture.

WHY IT MATTERS

Guests' desire to have fewer interactions with human staff has extended from the check-in desk to wanting to walk in and out without needing to speak to anyone at all. For the worn-out business traveler, a more frictionless stay could be especially nice. This could also be of benefit for anyone in the travel industry working off-hours or arriving early in the morning or late at night, worrying if the night manager will be available and responsive. With new management systems, guests will now select the number and type of interactions they do want to have with humans—and choose where and when. New booking practices will need to include this option for guests to select, and hotel staff might also need to ask that question upon arrival. On-site technology repairmen will also become more of a necessity due to the increased integration of humanless technology, in order for the experience to stay smooth. These technicians might also need to be more than repairmen if the frictionless stay includes digital wellness treatments or in-room cooking and dining.

HYPER-PERSONALIZATION

WHAT IT IS

On-premise staff, rooms, and spaces are utilizing technology to know guests' preferences on a granular level; this includes predicting what guests might want before they even know themselves.

HOW IT WORKS

Data to enable personalization is becoming more of necessity to increase profit and generate guest loyalty. While a report from Sojern found that over three quarters of hotels have seen an increase in revenue after enabling first-party data acquisition, privacy of the data remains a concern. PassiveBolt offers a solution: a single travel profile that can be used across multiple sites, services, and operators to know more about their guests' preferences. Since it's a decentralized data storage platform, guests can turn off access to their data at any time.

Predicting guest needs is also an increasingly needed skill. A recent patent looks to use AI to predict when guests will arrive while also integrating data that guests provide to choose the type of room they would prefer and make other optimizations for their stay. Facial recognition is another technology enabling greater personalization. Using Google Glass, Itesso's staff can instantly recognize guests and know how to personalize their interactions. Similarly, Hapi Guest uses its platform to give front desk agents more information about guests while they check in.

WHY IT MATTERS

Hyper-personalization is not new, but with new developments in technology it will scale to provide personalization on a microscopic level. Guests' expectation of hyper-personalization will continue to grow as they experience what it's like to stay in a place that knows them perhaps even better than they know themselves: Their data is used to make sure food shows up before they ask, and they are offered a wellness treatment due to their stress level. Consider this the next level of stars and ratings. Hyper-personalization could become a differentiating factor in how guests search for hotels, inquiring about the levels of personalization that are offered, which would need to be standardized by the industry as a whole. It will also impact when staff are working based on a guest's preferences. Loyal and frequent guests will come to expect certain staff to be present when they arrive or be ready to offer a desired service. This could impact scheduling for staff who are experts on preparing a specific food dish or administering a wellness treatment. Technologically enabled regional personalization could become a draw for tourists who are looking for consistent but more worldly places to experience.

PRE-EXPERIENCING THROUGH VIRTUAL TOURISM

WHAT IT IS

Travel is no longer just about going to a physical destination. Increasingly, customers are using virtual vacations and tourism in lieu of IRL traveling. Hotels are using virtual reality tours to entice guests to stay at their facilities, and this concept now extends to pre-experiencing events and other on-premise happenings for further enticement.

HOW IT WORKS

Recent research shows that guests rely less and less on reviews, and VR plays a major role in influencing their expectations before they travel. This trend is growing with examples such as Radisson's 3D virtual venue for guests to explore the hotel and even book their room, Atlantis Dubai's Virtual Tour that lets guests see the quality level of the experience they will have at the resort, and The Grand Oasis Hotel's 360o Hotel VR Tour. Omni Hotels has found that these types of virtual tours can increase booking conversions from 16% to 67%.

Staff is also becoming integrated into this trend, like at Le Franschhoek Hotel & Spa, where a 360 VR tour offers potential guests the ability to meet the manager. With increasing virtual events, these experiences are also being hosted in the metaverse. RendezVerse is working with Marriott and Atlantis to replicate their hotels in the metaverse for virtual conferences. This type of virtual tourism is also being explored by Wander, which is creating VR travel options for exploring ancient wonders, traveling by train, or touring museums.

A recent patent also explores linking the real world with the virtual by using VR, cloud real-time monitoring, and robotics to give skiers the experience of a ski resort's live conditions in the metaverse. This could enable other services like those of UrVenue, which creates 3D maps of pools, event venues, nightclubs, lounges, and more for guests to try before booking.

WHY IT MATTERS

Try-before-you-buy has become an expectation in retail, and the trend has now expanded to drive guests and tourists to a location. Guests will want to try their room first—to see the view or feel the bed firmness—and might also want to be walked through what their whole stay will look and feel like, which could be a paid add-on package. This capability, bundled with other personalized services and offerings, can create new travel and tourism packages and support events and conferences. Locations offering this service can pay a small fee to allow registrants to vote on which location they prefer based on the pre-experiencing offer. Pre-experience sales will help increase booking conversions, an incredibly important development when planning future conventions. It will also allow for customer feedback that can help operators know their areas of deficiency. Companies that manage booking sites and get paid by the rooms booked for these conferences should be capitalizing on this now if they are not already.

BUSINESS AUTOMATION

WHAT IT IS

From addressing staffing challenges to increasing sales to providing new means of safety, new technology is augmenting hospitality business practices and efficiencies.

HOW IT WORKS

Automation is essential for creating better business flow. New platforms from Best Western are allowing guests to tip staff through eTip, reducing some financial processes. PricingServiceAI is automating pricing for rooms, using market data to update every few hours. In the back-of-house, facial recognition technology is making it easier for staff to clock in and out as well: FaceMe installed at staff entrances can check employees in and also check body temperature, which can be helpful during future health crises. Staff automation can also be seen through a patent for a housekeeping system that will use AI sensors in a room to know what needs to be cleaned and directs a robotic cleaning staff to complete the necessary tasks.

Other forms of augmentation are occurring through blockchain technology like LockChain, a decentralized subscription-based platform to help make property rentals more secure. According to the 2023 Lodging Technology Study by Hospitality Technology, 70% of respondents were looking to add, upgrade, or change property management systems. New investments into management platforms like Germany-based Betterspace are providing better staff optimization and customer communication, and will be used to help enhance their energy management platforms.

Technology is also now making pools safer. Coral Smart Pool is providing MYLO, a virtual lifeguard for hotels. Leonardo Hotels are implementing this system to detect if there is a drowning incident or dangerous situation, which triggers an alarm in the pool and the hotel lobby.

WHY IT MATTERS

With tourism increasing and labor decreasing, finding new ways to run the business—while also providing better experiences and collecting data—will continue to be of vital importance in the hospitality industry. New systems that optimize when staff needs to be present, and provide seamless payments for those staff members, will make working at those locations more desirable. These automated systems can also improve data integrity and veracity, meaning that the data collected can be trusted for informing future decisions. These reports will provide critical analytics that businesses will need for knowing where performance and satisfaction are lacking or exceeding expectations. They can also support targeted marketing campaigns based on the data collected through the automation processes that correlate to new promotions during offseasons or for repeat guests. Besides all this, automation can also help with dynamic pricing and real-time updates that can lead to maximum revenue generation. Prioritizing the right automated system and where it should be implemented first deserves to be a carefully considered decision within a long-term strategic plan.

SCENARIOS

The Mobile Passport Concierge

The Juan family eagerly opens their latest purchase, a sleek-looking glass screen slightly larger than a tablet greets them in their preferred language. It's their new Mobile Passport Concierge, or MPC. "Welcome to a new traveling experience, Juan family," it purrs.

The glass projects an amalgamation of the family members' faces and continues to speak. "Please place your fingers on the screen or speak your names so we can verify your identity." After each member uses their preferred biometric to confirm their identity, MPC smiles. "Thank you. Now, as I have been given access to your shared calendars, I see that the big family vacation is coming up, but nothing has been planned yet. Is that correct?"

The Juans all nod.

"Fantastic, that is exactly what I hoped to hear because that's what I do best. I will plan it all in 15 seconds or less! Based on the data you provided when you signed up for Hilton's Curated HotelKey service, I am going to find a Hilton location that offers an immersive experience for Carlos, a 3D bio-scan for Lyla, a room that offers light and sound sensitivity screens for Miguel, and a restaurant that monitors food waste for Rosa. Here we go!" The MPC projects images showing a virtual worldwide search until it lands in Madrid. MPC chimes, "This is one of the newest nomadic destinations in Madrid and meets all of your specialized requirements and desires. It was built in under three months and travels to a new spot around the city every few years."

Very excited, the family books the trip, until MPC comes back with an alert. "I notice that Carlos' passport will expire during your vacation. Shall I update it now?" Carlos gives his consent, to which MPC replies, "Very well. Please also remember to take me with you throughout the airport as I will manage your tickets, any further passport updates, and fill out your travel visas. For now, please sit back and enjoy a quick video of the potential memories you could create."

With that, the screen is divided into four panels, and each family member watches a curated movie of themselves on their future vacation.

AUGMENTED RESTAURANTS AND DINING

1ST YEAR ON THE LIST

CONTACTLESS PAYMENTS

WHAT IT IS

Restaurant patrons can now pay for their meals with new forms of integrated payment. This is being offered through biometric and other forms of contactless payments.

HOW IT WORKS

Persistent concerns with surface sanitization have changed the way customers want to pay for their food. Most restaurant and QSR patrons prefer to use contactless payments and self-service kiosks—and businesses do, too, because it frees up servers to spend more time helping patrons versus cashing out tables. Presto was one of the first companies to release a tabletop ordering system and handheld tablet for servers, which increased the adoption of this trend. It has since evolved to allow customers to order and pay for their meal at the table with near-field communication (NFC) contactless cards and digital wallets.

Many restaurants and QSR chains are exploring using contactless forms of payment, such as biometric payments that include gesture, pay-by-face, or pay-by-palm. Panera is rolling out pay-by-palm capabilities for reward members to 2,100 locations. Steak-n-Shake is allowing 500 of its locations to use pay-by-face, and plans to expand this technology to another 300 stores. In one instance, at Pho Banh Mi Che Cali restaurants in Los Angeles, customers can opt for either paying by face or by palm. Some restaurants are also experimenting with bitcoin payments, sometimes through QR codes at the table. This builds off of systems like the Sunday app that launched during the pandemic. QR codes are now being discreetly placed on the table to offer promotions or take patrons to secret menus as well.

WHY IT MATTERS

Even though many restaurants are actually reducing their payment options, consumers are starting to push for more. Some are asking for biometric payment options for convenience, and to make their experience quicker and frictionless. So, there could be a rise in expectation for gesture and mid-air haptics technology at kiosks and checkout counters. This all comes at a time when credit cards are beginning to cost restaurants more in transaction fees and customers are taking note when the fees are passed on to them. The new forms of payment could create less friction and quicker processing. Covert menus and easier payment options will become more appealing to patrons who are looking for new experiences with little time to spare. As kiosks become more popular within QSRs for faster customer experiences, this reduces front-end personnel needs—for some. Being aware of your demographics and allowing for those who choose to still have face-to-face interactions will be key to not exclude one consumer group over the other. Companies should begin to establish preferences for various forms of biometric payments now to help familiarize their current and future customers with this new way of paying today.

AUTONOMOUS RESTAURANTS

WHAT IT IS

Some kitchen, waitstaff, and ordering activities can now all happen with very little human intervention. This includes product ordering and prep work.

HOW IT WORKS

Automated drive-thru ordering is beginning to become mainstream with companies like Wendy's, McDonald's, and White Castle rolling out AI to take over the ordering process. ConverseNow offers solutions for others looking to automate with two AI personas, George and Becky, which can have human-like conversations. Drive-thrus are also becoming smaller and more automated with conveyor belts, such as at a new McDonald's prototype in Fort Worth, Texas: It has a smaller footprint, and patrons pick up their food at a dedicated window from a conveyor belt. At Wendy's, delivery to cars in the parking lot is also looking different as it tests underground tubes and robots for food delivery.

Processes have also become more automated at restaurants and QSRs. Yum Brands is using AI to automate the kitchen flow, ordering, and delivery for thousands of its Pizza Hut locations. In the front-of-house, servers are now using wearables that receive notifications from the kitchen or Presto's tabletop ordering systems when patrons need refills or if they have allergies. For the back-of-house, Convo-Sense offers AI that can automate the cooking and baking systems by recognizing the food put into the cooking equipment and automatically launching the correct preparation.

From Matradee—using lidar to carry food and work around humans—to Servi—serving food and drinks—to Cecilia—speaking 40 languages and serving up to 120 drinks in Israel—robots are automating more functions in restaurants and QSRs.

WHY IT MATTERS

As patrons continue to accept less-human interactions when they see a return on their valuable time. These automations will be seen as a way to offer better efficiency for customers, help reduce errors, and potentially increase hygiene—all priorities for customers. They could open up possibilities for dark restaurants that function 24/7, a useful development for more mobile populations, transportation professionals, and vacationing families. Yet automation could also become a sticking point for companies considering whether traditional sit-down-dining or autonomous restaurants offer a more lucrative path for either franchising or setting up a subsidiary brand. With a more mobile and connected world, however, automation offers the potential for consistency of experience no matter where patrons engage with your restaurant and food. It can also help the current issues due to a reduced labor force. However, it will shift future generations' expectations of what dining experience should look like and adds a layer to the categories of traditional, QSR, and now autonomous. Established QSR brands trying to become more efficient will want to consider hefty renovations to turn human-run locations autonomous.

1ST YEAR ON THE LIST

EVERYWHERE ORDERING AND ANYWHERE DELIVERY

WHAT IT IS

Customers can order food for delivery almost anywhere now, especially with new tracking software and apps. This trend includes voice ordering, the use of kiosks, live tracking of deliveries, and new forms of delivery for restaurants and QSRs.

HOW IT WORKS

Like other areas of the industry, voice ordering is becoming more integrated in the food ordering process and will become ubiquitous. SoundHound's new partnership with Oracle will further enable voice ordering at more point-of-sale locations—the platforms use AI to help patrons order and get information on deliveries and locations. Customers can dictate their order from Uber Eats to Alexa devices, and then ask those devices for delivery updates. Through a partnership with Yobe, PLNT Burger uses kiosks with voice ordering to ease how patrons order. Grubbrr, a Florida company that offers self-ordering systems, claims that AI in kiosks can actually increase the amount of money patrons spend, which has been corroborated by other studies.

For deliveries, Whataburger partnered with geofencing provider Radar to enable the QSR to know when patrons arrive to pick up their food. Domino's launched its Pinpoint Delivery system, which lets patrons select their exact delivery location, expanding the chain's delivery offerings. Flytrex could help with this endeavor as well, as it is offering drone delivery to US suburbs for any need, including coffee. Alternatives to major delivery platforms are also expanding. Coca-Cola's minority stake acquisition of Thrive in India signals that more restaurants in that region will soon be able to create their own direct-ordering platform. And with apps like Wonder, cooking can also happen nearer to customers, even just outside their home in a van. In an interesting take on ordering, a new app launched at CES lets you designate a time and a place to use a nearby restaurant's bathroom.

WHY IT MATTERS

Ordering systems now need to be integrated into more locations and be interoperable so that restaurants and QSRs don't lose out on patrons who want to conveniently order from anywhere, even while walking down the street. The granular bifurcation of delivery spots presents both challenges and opportunities. Customers may expect mobile delivery, which means delivery drivers will have to track customers, versus customers tracking drivers. This reversal of roles means that customers will share new forms of data that could help autonomous restaurants or mobile locations to serve those areas. Voice biometrics could become more important for verification services, with customers expecting you to recognize their voice and have their order ready based on them saying hello. While this type of data could give businesses more data to know their customer's needs, it also presents many issues for collection, storage, and privacy. Restaurants will need to establish guidelines for where ordering should occur, and might need to have new technology that helps resolve background noises and garbled messages, or that can offer live translation for customers who speak a different language. With drones and food preparation bringing food directly to the consumer, this also shifts service experiences, which have largely yet to be defined, and could be a way to differentiate these new offerings in the market.

1ST YEAR ON THE LIST

MONITORING FOOD WASTE & IMPACT

WHAT IT IS

As climate change creates fear that food resources will be disrupted, many are focusing on being more responsible with their food waste. Many restaurant industry-focused startups are providing platforms for monitoring and mitigating food waste.

HOW IT WORKS

Increasingly, companies are interested in where their food waste ends up. Berlin-based Choco's streamlines the food ordering process, and monitors waste and food inventory. Other companies are using blockchain technology; Connecting Food uses food traceability data to track products going through the production line to audit the food, manage suppliers, and create a digital twin of the product, all with the aim of increasing consumer confidence. Currently used by Wendy's and McDonald's, Bolivian software company Mojix uses blockchain to automate food safety compliance, manage expiration dates, and reduce waste. It covers the lifecycle of an item to help provide traceability throughout the supply chain.

Therma provides services more directly to restaurants by offering IoT sensors for 24/7 temperature monitoring and an app that can help reduce waste and improve food safety. Brands including TGI Fridays, Domino's, and Wyndham Hotels use Therma to help protect their food inventory. Orbisk, a Dutch startup, puts a camera above a trash can to scan waste to help restaurants know their disposal patterns. Kilmato, based in Sweden, helps provide more data transparency for menu items: Their web-based app allows restaurants and QSRs to calculate the climate impact of their food and dishes and then label them to tell customers the carbon impact of their food. While focused on the grocery store rather than the restaurant, new AI scanners from a Dutch entrepreneur let customers scan avocados to see if they are ready for consumption.

WHY IT MATTERS

ESG expectations are impacting businesses in a variety of ways, with many responding by publicly sharing their procurement, labor practices, and waste management. These systems and technology tools can help food producers, restaurants, and QSRs provide data to prove they're being responsible with their food waste. They can help now, but could ultimately be disrupted with the advent of more additively made food sources and materials, and it will be important to watch how restaurants balance these forces. In the near term, these new systems also offer opportunities for cost savings that can assist in addressing overuse and over preparation of food. In many regions, there are new regulations and requirements for this type of monitoring, and these tools can provide the data needed to show that companies are in compliance. For companies looking to tap into younger generations that care more about responsible consumption, addressing these issues will prove to be a beneficial marketing tool.

IMMERSIVE EXPERIENCES

WHAT IT IS

Eatertainment has evolved from breweries to be either mobile or permanent dining experiences that use technology to elevate the room, table, and decor.

HOW IT WORKS

Dining experiences continue to push the boundaries with more immersive experiences that have become their own version of performance art. Technology enables these experiences to move beyond just tasting, to even include using food to experience emotions. Philadelphia, the cream cheese maker, created a sensorial experience that uses visuals and sound, along with cheese dishes, to let customers experience a range of feelings and different emotions. In Silicon Valley, iChina is debuting the first headset-free VR dining experience that will pair visuals based on the food that's served. At the restaurant Ultraviolet, diners will enjoy 20 courses throughout the evening while the room shifts with projected images, changes in lighting, music, and scents. Inside Hard Rock Hotel Ibiza's restaurant, you'll find not only chefs but also directors and musicians. The guests will explore various places, times, and emotions over three hours through a VR headset at one of the world's most expensive restaurants at around 1,800 pounds ($2,345) per person. Tablemotion Studios is already known for its experiences at the SLS Hotel Beverly Hills and Four Seasons Hotel Austin, but the company will debut a new interactive experience at The Culinary Institute of America at Copia in Napa and the Ritz-Carlton at Half Moon Bay in California. This new experience took over 50,000 hours to create; it uses visuals with 4K resolution and laser projectors.

WHY IT MATTERS

As restaurants look to differentiate themselves by using technology to replace human-to-human contact with human-to-automated contact, these immersive experiences could become smaller in scale to still allow for more engaged experiences and storytelling. Along with more interactive social media marketing and selling, these immersive experiences could offer customization through social selling, which can provide new data to help companies adapt to market trends. They also provide revenue diversification as restaurateurs and even QSRs can separately sell both food and experiences. Immersive experiences are currently focused on high-end dining locations but could grow and scale to augment QSRs, or even autonomous restaurants. However, focusing on the storytelling and the "why" behind the experience will be key for companies to get this right. Some experiences may not make sense, especially if they seem extravagant given current world issues like war or climate change. But for hospitality venues looking to attract conferences or companies looking for new ways to impress clients, these offerings could become a norm once they become scalable—and extend to digital wellness offerings at both restaurants and other hospitality locations.

SCENARIOS

Eating Darkness

As autonomous QSRs have taken over in fast-casual dining, Eating Darkness experiences began to dominate some traditional dining establishments. Many restaurants realized they needed to counterpoint to the tech-driven experiences many diners chose throughout the week; it started with lowering lighting levels over the course of the meal until the guests were eating in complete darkness but soon became augmented with technology that focused on visual well-being and comfort that increased the importance of the food the patron was eating. Now, many patrons choose Eating Darkness as part of their reservation, which means that they are offered a lightweight diminished reality band to don as they sit. They use it to choose the level of activity they see around them throughout the course of the meal, and their awareness will slowly fade to focus on just the food. Some describe it as a quiet hug and a shift away from the hustle and bustle of the world around them. The band facilitates the guest's order through voice ordering, and then provides a choice of ASMR noises, which also grow fainter throughout the meal. While this is good for single diners, cordoned-off diminished reality rooms are available for groups that provide the same experience, but are based on the group's shared preferences.

ENGINEERED FOOD AND MEALS

WHAT IT IS

As a means for better health and sustainability, many restaurants are working to incorporate and offer lab-grown and engineered food. Some foods and meals are being engineered for specific customer engagement experiences that go beyond dining.

HOW IT WORKS

Many companies are providing engineered food and meals to both restaurants and individual customers. In 2019, Foodadvisor began giving customers the ability to see what they are eating and to analyze its nutritional value. It also provides customized plans and advice on how to meet personal goals. SnapCalorie, a startup founded by the creator of Google Lens, plans to do something similar by using AI to estimate the caloric content of food based on a photo. What makes this app different from the rest is that it claims it can measure portion sizes.

Within 3D-printed food, several companies are working to bring engineered food to the mass market. Vienna-based company Mycorena has launched its whole-cut vegan salmon filet. This filet relies on new technology from Revo Foods that uses extrusion methods to integrate fats into fibrous proteins in a first-ever continuous production process for mass production. Researchers at Columbia University have combined 3D printing and laser technology to create and bake the first 3D-printed cheesecake; while this technology is not new, the researchers are considering what it would mean to create recipes like this for the masses to be able to download and use. Open Meals first began producing biometric 3D-printed meals in 2019, but it is looking to expand with a fully autonomous restaurant with their products by 2035—and with the possibility of AI-controlled 3D printers, could be available as a common kitchen appliance by 2040. Other foods being 3D-printed include chocolate, pasta, chicken, and steak.

WHY IT MATTERS

With personalized nutrition and food allergies increasingly in focus and a concern, 3D-printed foods offer new possibilities for alternatives and food prep. This can help reduce potential for cross contamination, as long as the materials used for the printed food are managed and monitored as well. The challenge will be the visual aesthetics of these foods and consumers accepting that their traditional cheesecake or meats will look different but taste the same. This is ultimately something that should be consumer tested and trialed, from which companies should create large-scale marketing campaigns. Since engineered meals and foods also offer more sustainability and nutritional capability, if they can be printed to taste the same as unhealthy or nostalgic foods, they could potentially make unhealthy food less attractive. The control of taste will become the key driving factor for success or failure, meaning customers will want their dish to taste different than what their neighbor might be tasting. Such an achievement would unlock new potential for customized experiences and foods. While the culinary world is constantly trying to innovate, this offers a new arena for new types of chefs and business offerings. Scientists and material fabricators could become the culinary geniuses of tomorrow.

VERIFIED LOYALTY PROGRAMS

WHAT IT IS

Digital loyalty programs are increasingly looking to blockchain technology for verification of customer spending and offering new rewards for those engagements.

HOW IT WORKS

Many loyalty programs are utilizing technology for increased engagement, and blockchain technology is at the forefront for many companies. One new offering is Blackbird: a loyalty program that gives partner restaurants a digital card to track and verify when customers visit and what they eat on Coinbase's Base blockchain. These programs allow restaurants to create any kind of loyalty program they want: They can be free and help track the number of visits, or paid and used to offer perks and experiences. KitchData, known to enable delivery-first food brands, is now offering their clients the ability to create NFTs, SMS crypto wallets, and other Web3 offerings through Harmony.one's blockchain.

Companies are now exploring facial recognition technology to create more personalized experiences for loyal customers. Diners can choose to participate, and, in doing so, be recognized when they arrive at the restaurant. FaceME is one such platform that can offer this to restaurants, and it can be integrated into kiosks and other customer touchpoints. Tattle, a customer experience improvement platform, is working on new ways restaurant companies can get data from their customers by offering programs to incentivize customers to scan their receipts.

WHY IT MATTERS

These new loyalty programs can obviously help increase customer engagement and retention, and can also provide an attractive experience to draw in new customers. The data and insights on customer preferences collected will be a critical component that companies will be able to understand and influence. The programs can also potentially reduce administrative costs as they become fully automated. The use of blockchain also provides consistent transparency, which will build trust among customers—but it will be key for companies to discuss and understand what level of transparency will be required. Past attempts at loyalty programs should also be a consideration because what may not have worked in the past may become functional today with these augmented offerings. The verification offered through blockchain technology further enables customers to have a frictionless dining experience, with the goal of creating diners who not only purchase food from the restaurant but also visit the restaurant's physical location.

CURATED TASTING

WHAT IT IS

AI and other technology are being used to craft menus and meals customized to individual customer preferences.

HOW IT WORKS

Personalization is growing in the restaurant industry, with AI offering new ways to customize your dining experience. Hungryroot, based in New York City, uses a quiz to identify what food you should order from the grocery store. AI platform Nutrios creates a custom page that then offers curated meal plans and personalized food recommendations. AI is also being used to make menus better. Lunchbox is a tech startup that uses AI to generate food images for restaurants to incorporate into their menu. Focused only on the restaurant industry, website platform company Superorder has worked with over 1,500 restaurants to create a website based on typing in a simple query.

Robotics may soon offer more personalized food that tastes best for consumers. A recent patent is exploring using AI to determine when a dish has met the right flavor requirements using particle data. Beko and the University of Cambridge trained a robot chef to know if food was too salty. The robot mimics how humans chew food in order to taste the food in a similar manner. You can now also taste your TV. A Japanese professor created a lickable TV screen that can imitate different food flavors; this comes after a researcher at Meiji University created a tool that allows a user to taste anything they want without having to eat the food. NTT Docomo, Meiji University, and H2L have also developed a unique technology that allows people to share tastes digitally.

WHY IT MATTERS

With curated tastings comes the opportunity for generating new experiences and customer retention through positive and personalized foods. The personalization of flavor means food may become individualized, similar to how engineered food flavors could become personalized; this could make it challenging to create a menu, unless you use AI or other automation tools. Eventually, we may see menuless offerings, where the menu is never posted or decided until the customer walks in to be served. All of these developments combined could become problematic for the back-of-house to create nuanced flavors—again, unless the capability is technologically enabled. These new additions to the tech stack will be hard to implement unless costs are shared or the company has deep resources. However, many demographics share the same taste profiles, which could be a way to target the implementation of certain curated tastings and menus. Globally, this would obviously change and be a challenge as well. Companies should also prepare for a future when ratings of personalized flavors become as influential as a review of the experience—the focus will shift away from styles or cuisine categories toward new flavor categories.

SCENARIOS

Your Chicken Soup for the Cold

Hello viewers, it's Chef Gordon Ramsay's avatar. Welcome to today's AR news segment, projected by your desk lamp sponsor. Our topic for you curated listeners who checked you like food news is about another food fad. In 2026, the latest craze to hit dining since butter boards and mood foods is chicken soup. People are absolutely going mad over chicken soup, lining up at any mobile pickup window they can find, or rushing out when their wearable pings that a new location has been set up near them. You may be confused, as many of us were at first, why chicken soup would be a fad-worthy food. It's because of the brilliant integration of medicine into Campbell's freshly printed soup paste. It sounds quite dismal but is actually on point because it tastes exactly how you remember soup from your childhood.

Yes, you heard me right.

When Campbell's entered the mobile QSR market with this product a year ago, I thought they must have lost their heads, but I was quickly corrected when I went for my first tasting. After a quick lick of the lickable menu, which analyzed my saliva memory, I spoke my order to the menu. It analyzed my voice to tell if I was sick, and then gave me a hot cup of curated soup designed to keep me well during cold and flu season. With the first sip, I could instantly tell this would be a hit. It felt like the recipe my mum used to feed me when I was a young lad. It created such a strong memory that I instantly went back to order the Campbell's Soup Dropper for all of my restaurants. The taste alone made it a fad, but the benefits of not having to take ill-tasting medicine when you are sick have also got customers salivating for this soup. It has become a bestseller for any restaurant that installs the Dropper.

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SUPPLY CHAIN · LOGISTICS

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TOP HEADLINES

Warehouses hire robot workers as nearshoring drives growth and manufacturing moves off-land. Driverless deliveries and innovative eco-friendly packaging are also emerging.

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Fulfillment Companies Hire Robots

Human workers in warehouses are increasingly finding themselves working alongside robotic workers.

02

Mexico Becomes a Nearshoring Target

Exports from countries experiencing nearshoring to their regions, like Mexico, continue to grow.

03

Driverless Deliveries Are a Reality

Automated delivery is now an expectation with companies like EASE Logistics piloting platooning in trucking transportation.

04

Packaging Is Not Just for Wrapping

Packaging patents are trying to make disposal a more eco-friendly process— and even edible.

05

Manufacturing Moves Off-Land

Through ongoing research in additive manufacturing, researchers have found ways to manufacture more effectively in space and under water.

STATE OF PLAY

Spearheading a New Era of Advanced Automation and Crystal-Clear Visibility

After the pressure and volatility of 2023, the supply chain, logistics, and manufacturing industries are experiencing relative stabilization while dealing with ever-changing consumer demands, climate change disruptions, and labor shortages.

Illness and reduced staff are major reasons for delays and bottlenecks in supply chains. A concerted effort to attract new talent include creating better working conditions, training opportunities, and innovative recruitment strategies—some studies estimate that 87% of companies are trying such tactics to attract new workers. Consumers returning to in-store shopping have increased expectations for seamless and rapid fulfillment services like next-day delivery based on their online shopping experiences, and companies are looking to enhance their last-mile delivery platforms.

Investors and consumers keep pushing for supply chains to become greener, with a significant percentage of companies feeling the pressure to reduce their carbon footprint. As more companies—over 40%—make investments in electrification, resource management, and more sustainable practices, this will continue to grow. With 2023 being the hottest year on record, many of these industries are also experiencing disruption due to extreme weather and looking to diversify sourcing and procurement, along with reshoring, to address the issue. However, delays at ports and limited supplies of raw materials have combined into a worrisome challenge for manufacturing. Demand for logistics and manufacturing space continues to increase yet soaring construction costs are a barrier.

Many of these challenges are putting the focus on automation and the use of technology for greater efficiency and visibility. The integration of the data needed to make automated decisions still proves challenging, and much of the data remains siloed. The largest push across supply chains and logistics for artificial intelligence and machine learning has been in inventory and network optimization, as well as warehouse resource management.

KEY EVENTS

APRIL 25, 2023

Colors determines quality
Researchers at the University of
Genoa are working on packaging
that changes color depending on
the quality of the product inside.

JUNE 15, 2023

Delivery robots require no humans
Cartken's delivery robots can now
use AI for full Level 4 autonomy on
sidewalks.

AUGUST 9, 2023

Revolutionizing automated routes
The EPG-Greenplan partnership reaches a
milestone when logistics provider DANX
starts implementing Greenplan's innovative
"overlapping" algorithm in Denmark.

MAY 17, 2023

Driverless deliveries take off
Ohio-based EASE Logistics announces its
launch of the first autonomous trucking
haul in the US.

JUNE 28, 2023

Parabola lands funding
Parabola makes automating manual processes
easy to manage, regardless of a team's technology
proficiency.

LIKELY NEAR TERM DEVELOPMENTS

ON-DEMAND DRIVES INSTANTANEOUS PROCESSES

Change—whether from consumer demands, new technologies, or global shifts—is the one constant in the supply chain and logistics industries. It's what leads to new offerings and services, such as the industries' need to respond to the increasing expectations for on-demand and instantaneous deliveries, communication, production, and reports. Innovations in tracking and tracing goods, automation, and expedited and near-shored manufacturing are happening, but attention is still needed to address the shortages in capital and talent. Proper investment to meet the gaps through technology will be expensive, and could create a burden many smaller companies cannot bear unless they create a clear strategic roadmap. With talent droughts occuring in all three they will have to keep competing for talent and seek out workers willing to be upskilled.

Personalized Delivery Gets Automated

As delivery routes and last-mile deliveries continue to increase in speed and complexity, automation will let logistics companies create an intricate web of delivery offerings that can be unique to each customer.

Climate Insurance for Protection

As climate change continues to be a disruption, logistics providers will explore how they can insure against extreme weather events. These costs could be passed along to consumers who choose goods from more volatile regions.

Combating a Skills Drought

Increased automation and use of virtual agents raise the need for workers to to know how to manage new tech-enabled work and tasks. This upskilling could be done through remote learning and working opportunities.

Virtual Agents Take Over

With workers continuing to grow in scarcity, virtual agents will take over back-of-house work in the warehouse. These virtual agents will soon be able to oversee themselves and their cobot workers, reducing the need for human intervention.

Instant Manufacturing Meets Demands

With manufacturing locations moving closer to the consumer and e-commerce increasing, manufacturers need to consider how to create products in the exact spot as their consumers.

Verification Based on Values

Global conflicts, combined with consumers and businesses wary of supporting governments with values antithetical to their own will increase demand for verification of supply chains. Granular data collection and transmission will enable this shift in transparency.

11 MACRO SOURCES OF DISRUPTION
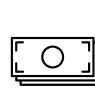
Technology	Media & Telecom	Demographics	Environment	Government	Public Health	Education	Geopolitics	Infrastructure	Economy	Wealth Distribution

WHY SUPPLY CHAIN, LOGISTICS & MANUFACTURING TRENDS MATTER TO YOUR ORGANIZATION

Track and Trace for Climate Accountability

As companies collect more data around their manufacturing processes, procurement procedures, and logistics for transporting goods, they will be able to create more in-depth reports to provide the level of transparency many governments and consumers require. This task can eventually be automated.

Streamlining Management Platforms

It can be hard to ensure multiple management platforms are interoperable, and that their data can be utilized across the system. An omnichannel platform synthesizes and streamlines processes and information into one concentrated tool, to establish consistent workflows.

Being Resource Resilient

While procurement gets disrupted by climate change and geopolitical conflicts, diversifying the procurement process and nearshoring can help mitigate future incidents. This will ultimately benefit the bottom line through customer satisfaction; however the upfront investment costs need to be charted quickly.

Communicating in Real Time

As consumers and businesses continue to monitor their goods and orders as they move through the supply chain and then through logistics channels, the ability to communicate changes in real time will offer a sense of stability and transparency. Ultimately, companies need to decide on the method for such communication so the information is clear and not burdensome.

Continuous Production

While e-commerce continues to increase, companies need to ensure the production of goods isn't interrupted or stopped. Continuous production through additive manufacturing can offer help in this area, and also sometimes reduce the raw materials needed to produce the goods.

New Management Needed

As cobots more closely resemble the typical worker, human managers might need new skills to manage them. Autonomous cobots can already travel without colliding into racks and other workers, but this technology will need to be monitored and probably further updated as warehouses undergo further developments.

OPPORTUNITIES & THREATS

Threats

Data silos will hinder the flow of information, and ultimately slow the automation process. Companies that have already managed to bring all of their data streams to one platform will have a leg up, and their data integration will support better decision-making.

Lack of raw materials will become a pressing issue for manufacturers that are not diversifying their procurement channels and taking climate change issues into account. Related delays will ultimately force customers to reconsider who they will purchase from.

As delivery routes get more complicated, they could be both too difficult for human delivery workers and too costly for autonomous delivery. If companies don't find the right balance, competitors will win out on savings realized from overlapping last-mile delivery routes.

Until it's fully automated, data collection could lead to bottlenecks and time-consuming processes. However, the granular level of data that needs to be collected cannot be hurried, especially as new EU regulations require presentation of the data before allowing the goods to pass through its ports or be sold to consumers.

Tech adoption costs will continue to deter modernization and weaken competitiveness. For companies that are market constrained and too focused on the bottom line, they may not see the long-term return on investment and miss out on investment opportunities.

Opportunities

Automation could augment production to help create goods more efficiently and deliver them faster. This can also offset talent shortages and help reduce costly errors that lead to recalls. It also helps with future preparedness.

Greater visibility means more efficient management of goods. Consequently, companies can optimize their inventory and thereby reduce the need for storage space. It also offers new ways to connect with customers and potential ways to upsell services.

Greater customer personalization can lead to renewed interest in lagging products. It also offers higher profit margins for goods that can be efficiently delivered. With more engagement and satisfaction, personalization data can also be leveraged to develop better products.

Amid talent shortages, staff augmentation and upskilling will create greater loyalty and better performance from employees, which ultimately impacts profitability and productivity. Augmentation will also improve future flexibility and workforce readiness as new technologies develop.

New forms of verification offer enhanced security and reinforces visibility and integrity with clients. As competitors work to mimic products and services, this level of verification can help reduce fraud and increase awareness of a company's specific practices.

INVESTMENTS AND ACTIONS TO CONSIDER

1

Consider investing in the automation of data collection and analysis. Prioritize the investment based on what tasks are being done in-house on the preferred platform, to avoid creating two sources of data that cannot be integrated. Such automation opens up more reporting and analysis of current processes for a strong understanding of what technology implementation should be next.

2

Upskill talent now so that they're ready to meet new technology needs—which could include how to manage or repair new equipment or cobots. This could become a new pathway to long-term careers and opportunities in your company.

3

Begin to investigate which cobot works best for you. Based on your company's size and scope of packaging and picking, this technology could serve different needs. Include strategic plans for future growth in this decision, or where staffing shortages are affecting your supply chains or manufacturers the most.

4

Optimize visibility that works for the customer. Cumbersome platforms with confusing reports only add to the overload of data most customers have to slog through. Use data to prioritize the channels your customers want and help them understand how to gain insights from the new visibility.

5

Invest in planning for new technologies that allow for better route optimization and last-mile delivery deployment. Watch regulations on drones and other forms of autonomous delivery, to help decide which areas to invest in first. Exploring both options now can prepare you to act when those regulations come to fruition.

6

Use your new data streams to offer insights that can improve your sustainability and responsibility messaging to your customers. However, this needs to be done in a way that is personalized to their needs, which means more micro-level and targeted communications.

CENTRAL THEMES

Automating Decisions and Processes

For companies working toward automation of decision-making and processes some are taking steps to bring their data into one knowledge bank. With variables like traffic jams, extreme weather, and fuel costs always at play, the logistics sector is most concerned with creating more efficient pathways for transporting goods. Progress in route optimization, coupled with autonomous vehicles, includes greater automated decisions on the flow of goods with minimal human intervention, and will ultimately lead to cost reductions due to fuel efficiency and less human error. For supply chains, automation of the routing and sourcing of raw materials, demand forecasting, tracking of inventory levels, and accelerating response times continue to be top ways to drive down costs and meet customer expectations. In manufacturing, companies are focusing their automation efforts on being able to make real-time process adjustments.

Closing the Last-Mile Gap

Companies in Europe, parts of Africa such as Keyna, and India are creating alternatives for more efficient last-mile solutions. Bangalore has seen the largest growth. With consumers demanding delivery within minutes to very granular locations, it's become a competitive imperative to innovate this expensive portion of logistics, with the ultimate goal of delivering value and speed to end consumers. Advances in AI for route planning and altering routes in real time are providing greater service and transparency for customers. Along with electrified transportation, micro-fulfillment centers are making progress on new last-mile methods. As companies experiment with using larger fleets of drones that can handle increasingly heavy items, this technology is combining with platooning efforts that could create swarm delivery for the last mile.

Authenticating Provenance of Goods

Customers and businesses can watch their goods throughout the entire process—from the time raw materials are picked up until they reach their final destination. Through new interconnected systems that provide real-time data, every step can be verified and recorded. Businesses and customers can possibly intervene if one step doesn't align with their needs, values, or expectations. Ensuring authenticity and compliance through this visibility is crucial and is happening through the use of new labels, product passports, and sensors. Also crucial is how the collected data gets managed and used. It can help prevent future bottlenecks if it can be integrated into platforms that offer the required visibility.

CENTRAL THEMES

Improving Warehouse Efficiency

In warehouses, delays can come from many sources such as injury or unexpected surges in demand. Responding to this risk, warehouses continue to become automated, dark, more connected and, in some cases, smaller. Whether they're using drones to scan packages and track inventory, automated picking, cobots that package the pallets, or augmented wearables for worker safety, warehouses are becoming more efficient. This efficiency is augmented by sensors that can tell if goods have spoiled or there is damage within the container. With such tools, tracking inventory and managing inventory levels is becoming increasingly efficient and more manageable, and a synergistic ecosystem is developing, where each technology reinforces the other. Additive manufacturing also helps create more efficiency by freeing up more space for storage of parts only when those parts are needed.

Hiring Robotic Staff

Each year, cobots become smarter, more autonomous, and more prolific, and this year is no exception. In fact, the first humanoid robot factory is set to open and produce 10,000 robots a year. These robots that work alongside human workers are being trained on more data that allows them to adapt and work around their human counterparts. Developers have focused on improving cobot safety measures, so a cobot knows what to do if it bumps into an unexpected obstacle or person. These cobots mitigate potentially harmful work for humans by either augmenting the human body or replicating repetitive tasks that could cause future injuries. Some of the augmented wearables can also offer predictive pathways through the warehouse to ensure worker safety. As autonomy continues to grow in robots and transportation, this trend will create newfound efficiencies and productivity, particularly during peak demand seasons.

The Intelligent Manufacturing Evolution

Manufacturing continues to transform from a traditional labor-intensive practice to a more sophisticated and interconnected system. Recent advances intend to create higher levels of productivity and efficiency, but they're also addressing sustainability requirements and enabling product personalization. The new tools and technology can spot flaws in products before they leave the floor, greatly increasing consistency for goods. Along with quality control, sensors and digital twins are getting companies to focus on predictive maintenance by reducing downtime during large runs or times of high demand. Additive manufacturing also allows for the integration of new materials that are themselves smarter and more connected. And it helps reduce the number of parts needed for production of a good, which can streamline production and reduce waste as only the parts needed are produced.

ONES TO WATCH

Dr. Alexandra Brintrup, professor at the University of Cambridge, for her work in data revolution within supply chain networks.

S. Vijay, assistant professor at Arasu Engineering College, for his work on autonomous drones.

Màrius Montmany and **Oriol Hernandez,** co-founders of Rever, for their work on instant refunds and label generation.

Arti Kütt, CEO of Cleveron, for his work on parcel robots and lockers.

Paola Lova, assistant professor at the University of Genoa, for her work on intelligent packaging.

Ioannis Kaloskampis, David Bradnum, Charles McGowan, Paige Hunter, and **Melissa Bui,** all of the UK's Data Science Campus, for their work using natural language processing and transformer-based deep learning models to construct supply chain networks from unstructured text.

Ieva Meidute-Kavaliauskiene, head of the Business Technologies and Entrepreneurship Department at Vilnius Gediminas Technical University, for her work in using neural networks within the supply chain.

Sehinde Afolayan, founder of Haul247, for his work in creating an end-to-end logistics platform in Nigeria.

Jörg Lamprecht, executive chairman and founder of Dedrone, for his work on a global network of urban drone detection services.

Antonio Spears, co-CEO at City Global, for his work on augmented reality technology in product development.

Mor M. Peretz, Dr. Alon Cervera, and Dr. Eli Abramov, co-founders of CaPow, for their work in bringing perpetual power to autonomous robots.

Ali Ekti, researcher at Department of Energy's Oak Ridge National Laboratory, for his work in the development of low-powered sensors for pavement markers.

Sachin Sharma, doctoral student at Western Michigan University, for his contributions to the research on autonomous driving technologies.

Zachary Asher, assistant professor of mechanical and aerospace engineering at Western Michigan University, for his work on pavement markers supporting autonomous driving in tough conditions in remote areas.

Dr. Emma Yang, assistant professor at The University of Texas at Arlington, for her work on hybrid additive-subtractive manufacturing equipment.

Dr. Raymond Weitekamp, founder of PolySpectra, for his work on generating stronger 3D printed materials.

Pascal Bensoussan, chief product officer at Ivalua, for his work in AI-powered contract digitization and purchasing optimization.

IMPORTANT TERMS

Additive manufacturing
A manufacturing process of creating objects by adding material layer by layer. It is synonymous with 3D printing but includes using reactive materials for 4D printing.

Customer relationship management (CRM)
A tool that manages a company's interactions with current and potential customers.

Enterprise resource planning (ERP)
Integrates all facets of an operation, including development, manufacturing, sales, and marketing.

Environmental, social, and governance (ESG)
Refers to the three central factors in measuring the sustainability and societal impact of an investment in a company.

Fulfillment centers
Warehouse facilities used to store, package, and ship consumer goods.

Last-mile delivery
The final step of the delivery process where a product moves from a transportation hub to the final delivery destination, typically a personal residence.

Logistics
The detailed coordination and implementation of complex operations involving the movement of goods, services, or information from origin to destination.

Order management system (OMS)
A system that facilitates and manages the order fulfillment process.

Product lifecycle management (PLM)
A software solution that manages the entire lifecycle of a product, from inception, through engineering design and manufacturing, to service and disposal.

Procurement
The process of sourcing and acquiring the goods and services a company needs to fulfill its business model. It involves the negotiation of prices, terms, and contracts for purchasing.

Supply chain
The entire system of producing and delivering a product or service, from the very beginning stage of sourcing the raw materials, to the final delivery of the product or service, to end consumers.

Transportation management system (TMS)
A system that plans, executes, and optimizes the physical movement of goods, both incoming and outgoing.

Warehouse management system (WMS)
A system that supports and optimizes warehouse or distribution center management.

SUPPLY CHAIN & LOGISTICS MANAGEMENT

AUGMENTED & AUTOMATED PROCESSES

WHAT IT IS

Supply chain and logistics providers are continuing to harness AI-enhanced automation and AI-augmented decision support solutions to stay ahead and capture value right from day one of implementation.

HOW IT WORKS

AI-driven supply chain management models can opt for either a data-consolidation approach, by harnessing extensive training data sources, or use multiple specialized models tailored to specific domains. Companies such as Mariner and Landing AI provide solutions for manufacturing—including defect detection—which work with limited and imperfect data sets. This approach differs from big data solutions from providers such as Kitov and Cognex, which work by ingesting huge quantities of data.

Parabola, a Series B startup, uses AI to automate complex manual processes through familiar spreadsheet functionality, and is usable by teams of all technical aptitudes. In the realm of cloud-based solutions, Adiona has created an Optimization Software-as-a-Service (OSaaS) that helps businesses improve their logistic processes while cutting costs.

Going even further, researchers at the University of Cambridge are developing a platform that can make decisions and autonomously act on behalf of stakeholders in supply chains. This system has virtual agents that bridge internet of things data and machine learning, possessing the ability to select suppliers, procure goods, and respond to unplanned events through pricing adjustments and automated rerouting. And Carrier Logistics Inc. has introduced AI-driven routing logic and planning optimization with a unique focus on terminal optimization for trucking fleets. The software features the ability to automatically plan shipments for every customer at every terminal, accounting for various factors like equipment, time windows, and traffic.

WHY IT MATTERS

Implementing augmented and automated processes significantly diminishes manual labor and human error, which translates into substantial cost reductions, greater efficiency, and an optimization of resources. It can also help make better, data-informed decisions. And by reducing errors and omissions, potential setbacks in the supply chain can be minimized. As access to automation grows, employees will gain the sense that they can more effectively contribute to growing the company and the bottom line. And automation can also prevent downtime-related losses by forecasting the least-disruptive times to conduct maintenance while extending the life of equipment through proper maintenance. Using automation to select suppliers could further increase efficiency but also lead to questions as to why those companies were selected in the first place. Defining the parameters for AI's selection criteria will be incredibly important. By optimizing routes and reducing unnecessary mileage, companies can reduce fuel consumption and lower carbon emissions, aligning with the growing importance of sustainability in the supply chain and logistics industries.

2ND YEAR ON THE LIST

REAL-TIME OPTIMIZATION

WHAT IT IS

Companies can increase the control of the flow of goods, maximize fuel efficiency, and increase sustainability when they are able to optimize routes in real time, while still delivering their goods on time.

HOW IT WORKS

Real-time supply chain optimization offers immediate insights, letting companies improve efficiency, reduce costs, optimize routes, and adapt to changing conditions. London-based Sensat creates digital twins for physical infrastructure; the digital replica updates in real time with automatic drone updates, camera feeds, and live data. Moving from visualization to real-time control, French company Zozio's ROBIN presents a real-time SaaS using IoT trackers to monitor product and equipment locations at every production stage.

Aera Technology has partnered with Colgate-Palmolive, aiming to provide a single source of truth for data across multiple sources, predict optimal product allocation, and prioritize fulfillment and safety stock demand.

Fleetroot's IoT platform offers real-time tracking, route optimization, and order management for fleets. In the realm of real-time fleet management, Nvidia's cuOpt, an accelerated optimization engine, can solve complex routing problems with subsecond solver response times for dynamic rerouting, job scheduling, and robotic simulations. It achieves world-record accuracy with a 2.98% error gap on the Gehring & Homberger benchmark.

Bettermile's cloud-based logistics platform distinguishes itself with features like real-time tracking, dynamic route optimization, and enhanced communication. Notably, it provides tailored solutions for specialized shipping industries, ensuring secure and punctual deliveries aligned with industry regulations. Lastly, on the note of eco-conscious routing, Greenplan stands out with its ability to optimize routes with a focus on diminishing carbon footprint while allowing spontaneous assignments in daily routes.

WHY IT MATTERS

Real-time solutions make it so companies can adapt to changing conditions, ensuring seamless operations and minimizing disruptions while containing costs. Businesses that embrace real-time optimization can consistently monitor and adjust operations, which will help them maintain high standards of performance and increase customer satisfaction. Innovations that solve routing problems or merge routes will achieve new efficiencies and previously unrealized areas of potential. This kind of dynamic routing could also offer the ability to create more dynamic pricing instead of fixed rates, depending on the level of efficiency that can be achieved. Because fuel is one of the biggest costs to these industries, this kind of optimization could result in almost immediate savings. But these real-time solutions can also dovetail to ensure transportation professionals do not exceed their allotted hours while providing greater insights on how they can maximize time on the road. Various conditions in the future such as sales, holidays, product runs, extreme weather, and traffic due to aging infrastructure could all be alleviated through the predictive planning these platforms offer.

2ND YEAR ON THE LIST

VISIBILITY TRACK AND TRACE

WHAT IT IS

Track and trace solutions let organizations and customers track movement at every stage of the supply chain, helping manage uncertainty and disruptions in real time.

HOW IT WORKS

Shipping track and trace is the backbone of modern logistics. In collaboration with British Telecom, Gorilla Technology Group has introduced a container identification and container damage detection solution; this innovation uses AI and machine learning to analyze video footage, identify containers, track movements, and detect damages.

DB Schenker has introduced ultra-thin tracking labels in partnership with Sensos. These disposable labels can be attached to containers, pallets, or cartons to enable real-time tracking of shipments across land, air, and ocean transport. They provide location and temperature data over the mobile network, ensuring security for valuable consignments.

DNA tags and traceability systems represent a novel frontier in supply chain security, offering atypical authenticity verification. Applied DNA Sciences employs synthetic DNA tags: Sprayed as a fine mist, they can be used for everything from tracking microcircuits for the Department of Defense to tracing cannabis supply chains, making it a potent tool against counterfeiting. Eurofins and Applied DNA Sciences have further partnered to pioneer a DNA-based traceability system in the leather supply chain. The unique molecular signatures of synthetic DNA tags make them impossible to copy, providing forensic evidence of product authenticity and safeguarding against counterfeit goods.

Continuing the exploration of supply chain security, Swiss startup ScanTrust combines secure QR codes and business intelligence software for supply chain data. Its QR codes facilitate anti-counterfeiting for consumers using just a smartphone and require no programming.

WHY IT MATTERS

Track and trace solutions are enhancing logistics efficiency and customer service. Synthetic DNA tags represent a significant advancement in supply chain security, by offering unparalleled authenticity verification and protection against counterfeiting, strengthening brand trust and traceability. Potential benefits include improved visibility into the supply chain for customers and better inventory management for companies. Companies can reduce excess inventory, lower storage costs, and optimize stocking levels based on real-time demand if they properly track their goods. But in the future, the technology could prove problematic as synthetic biology scales and DNA copyrights. The security for tracking will become even more important if supply chains continue to be disrupted, and companies will have to rely on their customers' faith in the business to maintain stability. Hacking of track and trace opens up new forms of digital piracy that should be a concern.

2ND YEAR ON THE LIST

ESG TRACKING AND DECLARATIONS

WHAT IT IS

With ESG tracking and declarations, companies can align their supply chains with their environmental, social, and governance goals, to foster transparency, responsibility, and sustainable practices.

HOW IT WORKS

As more companies make ESG tracking a priority, a flurry of VC funding has opened up for startups focused on ESG reporting and management. That includes Germany-based IntegrityNext, which helps companies audit their supply chains for ESG compliance, and France's SESAMm, which provides corporations with ESG insights into their supply chain. CarbonChain specializes in assisting industries with high emissions—such as agriculture, metal, mining, and oil and gas—to monitor their supply chain emissions. Companies upload their supply chain data on the platform and receive comprehensive emissions reports, complete with detailed breakdowns at the asset level and AI-generated sustainability insights.

Sheer Logistics introduced its own customized ESG dashboards that enable managed transportation clients to monitor real-time Scope 3 carbon dioxide emissions across all transportation modes in their supply chain. These dashboards aggregate transportation data, ensuring clients can accurately track, measure, and report emissions following a globally recognized standard developed by the Global Logistics Emissions Council.

In line with this trend, Apple released a new framework highlighting its progress on renewable energy adoption, efficiency improvement, and materials innovation. To do this, the company conducted in-depth analyses of the clean energy percentage used in manufacturing for each product and tracked the impact of expanded recycled materials usage on device climate footprints.

WHY IT MATTERS

ESG tracking and reporting ensure compliance with ESG standards, thus reducing the risk of regulatory issues, financial penalties, and reputational damage. ESG tracking is also a strategic asset in building a resilient, ethical, and competitive business. It can also help companies be better prepared for future risks to their resources in regions that are vulnerable to climate change. Making this kind of information publicly available enhances transparency and accountability, fostering trust among stakeholders, including consumers and investors. This is increasingly important as consumer awareness and concern about environmental and social issues grow; companies with transparent and responsible practices in their supply chains can significantly influence purchasing decisions. Furthermore, prioritizing ESG tracking gives companies a competitive advantage in the market. But it's not just about public perception: ESG tracking and declarations equip companies to better adapt to changing economic and environmental conditions, providing resilience against the challenges of sustainability.

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2ND YEAR ON THE LIST

OMNICHANNEL MANAGEMENT PLATFORMS

WHAT IT IS

A comprehensive platform that includes everything from warehouse management systems, to enterprise resource planning, to transportation management systems eases the responsibilities behind sourcing, manufacturing, and delivering products to customers.

HOW IT WORKS

Omnichannel, a pivotal strategy in modern commerce, seamlessly integrates varied sales and distribution channels to provide consumers a unified expedited experience while minimizing inventory. Recently acquired by Ingka Investments, the investment arm of Ikea, Made4net specializes in a cloud-based warehouse management system and end-to-end supply chain execution software. Its omnichannel fulfillment solution will boost Ikea's operations, enhancing order fulfillment accuracy and supply chain visibility across 482 locations. Target has also highlighted the success of its omnichannel efforts: In a recent earnings report the retailer boasted a 4% growth in same-day services and a 7% increase in drive-up usage.

Flowspace's software provides centralized visibility and reporting, offering modern omnichannel solutions to efficiently manage and optimize supply chain operations, whether a company uses its own facilities or Flowspace's network. And Maersk has introduced an e-commerce fulfillment solution that streamlines warehousing, order processing, and last-mile deliveries, ensuring end-to-end visibility and reducing the need for multiple logistics partners.

Omnichannel fulfillment also boosts order volume and necessitates quicker deliveries for smaller orders. Blue Yonder's Warehouse Execution System optimizes warehouse operations by efficiently allocating tasks to the appropriate resources, resulting in increased capacity and operational excellence. And Belgium's Alpega provides a comprehensive logistics system for end-to-end transportation services by facilitating real-time communication between manufacturers and logistics providers while streamlining transportation requests into a single system.

WHY IT MATTERS

Omnichannel management platforms are essential in the supply chain, logistics, and manufacturing industries for creating a cohesive and efficient consumer experience across various sales and distribution channels. By centralizing operations, these platforms greatly enhance customer retention and satisfaction. They skillfully balance minimizing inventory levels with maintaining product availability, which reduces holding costs and boosts the overall efficiency of supply chain operations. Centralized reporting features simplify the management and optimization of supply chain activities. Additionally, the cost-efficiencies introduced by these platforms span multiple facets of supply chain operations, including warehousing, order processing, transportation, and administration. Importantly, these platforms are designed for scalability, enabling businesses to adjust to fluctuating order volumes and smoothly expand operations. This adaptability is crucial for growth and meeting market demands, making omnichannel management platforms a strategic tool for businesses aiming to streamline their operations and effectively scale.

2ND YEAR ON THE LIST

DIVERSIFYING THE PROCUREMENT PROCESS

WHAT IT IS

Companies are expanding their supplier base to make it more inclusive and in line with their corporate values—which can also benefit their bottom line. They're achieving this through new technologies offering transparency and onboarding efficiencies.

HOW IT WORKS

Broadening the procurement process is vital to bolster adaptability and mitigate risks like supply interruptions and price fluctuations. Linkana streamlines supplier onboarding and governance with automated compliance processes, reducing the hassle of vetting new suppliers. Its methodology identifies diverse and inclusive economy suppliers, automates risk analysis, and provides access to a vast B2B network.

Delving into cloud-based solutions, Ivalua offers an AI-enhanced source-to-contract process that simplifies supplier risk assessment, fraud reduction, and contract analytics. Omnia Partners' Opus supports procurement with a simplified platform providing access to hundreds of cooperative contracts. Users can requisition from multiple suppliers in a single transaction and access real-time product data, eliminating the need for multiple websites or third-party platforms.

In digital procurement intelligence, Smart Cube's Amplifi PRO, an on-demand procurement intelligence platform, introduces AI/machine learning functionality for enhanced search capabilities. Users can post sourcing questions and get summarized responses within seconds. On a similar note, Scoutbee's Intelligence Platform incorporates generative AI features to provide deep insights into supply bases. NASA has introduced its Acquisition Innovation Launchpad to accelerate innovation communication, diversify the industrial base, and modernize procurement. With this initiative, NASA's focus shifts to modular procurement approaches, emphasizing safe risk-taking and agility to adapt to a fast-paced technological environment.

WHY IT MATTERS

Diversifying the procurement process is crucial in these industries because it significantly mitigates the risks related to sole-sourcing. By sourcing from a variety of suppliers, businesses can reduce vulnerabilities such as supply interruptions, price volatility, and weakened negotiation positions, thereby fortifying the resilience of their supply chains. Streamlining the supplier onboarding process through automated compliance procedures simplifies and accelerates the vetting of new suppliers, conserving time and resources. This automation not only facilitates engagement with a broader range of suppliers but also minimizes risks linked to new, untested suppliers, contributing to a more dependable supply chain. Additionally, a diverse procurement strategy yields richer data and insights, improving the efficiency and effectiveness of decision-making processes in the supply chain. Overall, diversification in procurement is not just a risk management tactic but a strategic approach to building a robust, agile, and data-rich supply chain infrastructure.

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LAST-MILE SOLUTIONS

WHAT IT IS

Companies are seeking to shorten the last mile to increase their margins. Several new advances in technology are offering faster solutions and increased range of delivery.

HOW IT WORKS

Last-mile solutions are the linchpin of modern supply chains, ensuring timely deliveries, cost-efficiency, and a superior customer experience while addressing urbanization and sustainability challenges. Manna, an Irish company, is tackling the last mile in the sky: Its all-electric, zero-emission drones have an average delivery time of three minutes and offer sustainable shopping options while prioritizing customer privacy.

For ground-level solutions, Cartken's delivery robots have achieved Level 4 autonomy on sidewalks, significantly reducing reliance on human operators and enabling cost-effective autonomous last-mile deliveries. AxleHire enhances last-mile delivery accuracy with its technology, helping cross-border e-commerce companies achieve next-day shipping upon entry into the US. Similarly, DeliveryDefense from UPS Capital uses predictive analytics to assess delivery risk associated with addresses across the US. It empowers e-commerce retailers to make informed decisions before shipping, enhancing the likelihood of successful deliveries. And Curri, which focuses on on-demand, last-mile logistics for the construction industry, offers nationwide fleet services for various load types, providing real-time tracking, proof-of-delivery, and comprehensive visibility.

Shifting to environmental impact, Estonian tech company Cleveron has introduced a battery-powered outdoor parcel locker that significantly reduces CO_2 emissions in the last-mile sector. Cycle, a B2B mobility solution for delivery services and couriers, enables sustainable last-mile delivery with e-bikes and has secured 10.3 million euros in Series A funding.

WHY IT MATTERS

Last-mile delivery solutions are crucial for ensuring timely and efficient deliveries—a key factor in meeting customer expectations and maintaining a competitive edge. They significantly reduce delivery costs by optimizing routes, decreasing dependence on human labor, and increasing overall delivery efficiency. Providing a superior customer experience, vital for fostering brand loyalty and encouraging repeat business, is another critical aspect of last-mile solutions. Technological advancements such as dynamic routing algorithms and predictive analytics play a significant role in enhancing the accuracy and efficiency of these deliveries, making them both successful and cost-effective. Moreover, the development of specialized last-mile services for specific industries, like on-demand logistics in construction, exemplifies the innovative potential of these solutions to meet unique industry needs. Last-mile solutions are not just a final step in the delivery process; they are strategic tools for improving customer satisfaction, reducing operational costs, and driving innovation tailored to industry-specific requirements.

2ND YEAR ON THE LIST

SMART PORTS

WHAT IT IS

The congestion at ports that arose during the pandemic has begun to ease, but concerns about the future have companies looking for new shipping routes, new devices for monitoring congestion, new smart technology implementation, and new ways to expedite loading and unloading.

HOW IT WORKS

Europe's two largest shipping gateways have begun a series of investments to manage increasing shipping activity. The Dutch port of Rotterdam, known as one of the best smart ports in the world, is expanding its fully automated capacity and hinterland connectivity, while the Antwerp-Bruges port has launched an extensive digital radar and camera network to manage its substantial shipping traffic.

Amid these investments, Awake.AI has introduced the Smart Port as a service platform, leveraging Intel technology, AI, and 5G to enhance operational efficiency in ports. The platform utilizes machine-learning models and sensors to provide real-time awareness of cargo flows, optimized port utilization rates, and reduced emissions.

The Port of Ponce in Puerto Rico is set to become a Smart Port Lab through a partnership with Scale AI. A $2 million project will develop AI-enabled port infrastructure, including document processing, route optimization, and object recognition. This initiative aims to modernize shipping and transportation equipment, unify shipping and port data, and enhance operations for the port.

In Asia, Langkawi Port is also focusing on enhancing its smart port infrastructure. It has partnered with CelcomDigi to use AI-driven safety and security solutions to analyze vehicles, create smart digital boundary control, and conduct general surveillance to ensure efficient and secure port operations. And Tianjin Port Group and Huawei are deepening their cooperation to create a digital twin of the port leading to Beijing. This initiative involves constructing automated terminals, upgrading traditional terminals, and making the overall port more automated and intelligent.

WHY IT MATTERS

Smart ports are using cutting-edge technologies like AI, 5G, and digital radar networks to revolutionize operations in the supply chain, logistics, and manufacturing industries. By providing real-time insights into cargo movements, these ports optimize utilization rates and streamline processes, leading to cost reductions and enhanced supply chain efficiencies. This shift marks a significant stride in the maritime sector's digital transformation, by incorporating the use of digital twins—virtual replicas of physical ports—for smarter, more efficient operations. Additionally, features such as vehicle analytics, digital boundary control, and enhanced surveillance bolster overall safety and security, mitigating risks and ensuring uninterrupted port activities. Smart ports also play a pivotal role in the global trend toward connectivity and interconnectivity. They enhance hinterland links and unify shipping and port data, facilitating the management of extensive shipping traffic. In essence, smart ports are not just about technological upgrades; they represent a holistic approach to redefining maritime logistics, emphasizing efficiency, safety, and global connectivity.

SCENARIOS

SCENARIO YEAR 2031

The OmniVision Chain

An immersive omnichannel platform called OmniVision has transformed how supply chain management controllers operate. Gone are the days of monitoring operations from a physical warehouse; now, controllers navigate a virtual landscape that mirrors the real-time dynamics of the global supply chain. Within the OmniVision environment, management controllers—equipped with advanced VR gear—stand amid a digital twin of the supply chain world. They observe a holographic globe where supply routes, manufacturing hubs, and distribution centers pulse with life. Through intuitive gestures, they zoom into specific areas, inspecting operations with incredible detail. They can visualize everything from cargo ships navigating oceans to robotic arms assembling products in factories.

One of the platform's groundbreaking features is real-time ESG reporting. Controllers can instantly access a site's ESG metrics and observe live data streams of energy consumption, waste management, and labor practices. This transparency enables them to uphold ethical standards and swiftly make informed decisions. When a worker strike or a disruption occurs, the controllers, with a mere flick of their fingers, reroute production to an alternative site. This instant transition is possible thanks to OmniVision's predictive analytics and interconnected global network. Customers, on their end, have embraced MyVisionLink, a personalized version of OmniVision that syncs with their preferences and purchase history, allowing for a harmonious interaction between consumer demand and supply chain responsiveness. This synergy ensures that product availability and delivery expectations are perfectly aligned, creating a seamless and satisfying customer experience.

MANUFACTURING & DISTRIBUTION ENHANCEMENTS

2ND YEAR ON THE LIST

CONTINUOUS ADDITIVE MANUFACTURING

WHAT IT IS

The production process known as continuous additive manufacturing streamlines the creation of items by constantly printing parts, thereby reducing downtime and enabling the efficient production of complex, customized products.

HOW IT WORKS

Continuous additive manufacturing drives a decentralized just-in-time approach to production. To address speed bottlenecks, start-up Ambots harnesses autonomous swarm robots for its solution, breaking down digital designs into manageable tasks through proprietary chunk-based 3D printing. Ambots is now leading the software development for a $3.5 million project that will 3D print horizontal mission structures for the US military.

For metal additive manufacturing, a collaborative research effort in South Korea has introduced a novel technology, enabling continuous additive manufacturing in various orientations. In another approach to 3D metal printing, Fabric8Labs, a San Diego startup, is developing electrochemical additive manufacturing. The room-temperature technique builds rapidly at the atomic level from a water-based feedstock containing dissolved metal ions. This approach allows for micron-scale feature resolution and complex internal features, and can print onto temperature sensitive substrates such as PCBs, silicon, or existing metal components.

For hybrid additive-subtractive manufacturing, a researcher at the University of Texas at Arlington is exploring equipment that could efficiently repair and remanufacture parts, even in resource-constrained environments like space. VulcanForms integrates additive and subtractive manufacturing, as well as in-process sensing and machine learning to enable an industrial scale laser metal additive manufacturing solution. It produces parts for companies in the medical, defense, semiconductor, and aerospace industries, turning designs into finished parts in a matter of days. Researchers at EPFL's Laboratory of Thermomechanical Metallurgy have validated the effectiveness of acoustic monitoring in laser-based additive manufacturing, enhancing product quality in industrial sectors using laser powder bed fusion.

WHY IT MATTERS

Continuous additive manufacturing is pivotal in cutting down on time and costs in the supply chain and manufacturing sectors. It also fosters a decentralized production model, enabling manufacturing at or near the demand point, minimizing transportation needs and costs. This method supports the production of customized products on demand, which is particularly advantageous for industries needing unique parts, such as health care and aerospace. Moreover, the hybrid of additive and subtractive manufacturing in one continuous system catalyzes innovation in fields like aerospace and defense, allowing for on-site component repairs and diminishing the reliance on complex supply chains for part replacement. It also expedites the R&D cycle, crucial for sectors that depend on swift technological advancements and adaptability. As this process continues to scale, it will create new forms of business services, and become increasingly important to the retail world. The selling of materials for these services also offers a potential new business venture, which would require large socialization efforts for consumer adoption.

2ND YEAR ON THE LIST

SMART WAREHOUSES

WHAT IT IS

Smart warehouses are technologically advanced facilities that leverage automation, AI, and real-time data analytics to optimize inventory management and streamline the entire supply chain process.

HOW IT WORKS

While IoT adds complexity to smart warehouses by generating vast amounts of data from various devices, edge computing supports a solution by processing all the data locally. Belgian startup Edgise is specializing in developing hardware for edge computing applications, enhancing AI processing speed in industrial systems, and optimizing processes by bringing AI closer to the data source. Another instance is Seattle-based Loopr, which offers AI-powered edge applications for defect scanning, maintenance prediction, and inventory management.

Digital twin solutions can also help, enabling real-time monitoring, analysis, optimization, and predictive maintenance. San Francisco startup Datumix offers a virtual 3D simulation and AI-driven digital twin for equipment condition monitoring, improving loading and unloading efficiency by up to 30%, and reducing labor costs by 15%. German company Cognition Factory also offers an AI-based digital twin solution for warehouse simulation.

Amazon is deploying AI-powered damage detection to its warehouses to speed up fulfillment: The company's computer-directed facility in San Antonio employs robots for inventory management, storing 18 million items at any given time and shipping 2 million items on a weekly basis. And in the spectrum of measurement innovations, MoistTech's implementation of near-infrared technology is a notable breakthrough. Through nondestructive, contactless analysis, it achieves an accuracy level of 0.1%, underpinning precise quality control and moisture management for optimized energy usage.

WHY IT MATTERS

Smart warehouses represent a significant leap forward for the supply chain, logistics, and manufacturing industries. Utilizing edge computing, AI, and digital twin technologies, they process vast amounts of data to optimize operations, demonstrating the critical role of advanced technology in logistics. Edge computing will become a necessity as it empowers smart warehouses by reducing latency, enabling real-time decision-making, and enhancing overall operational efficiency—ensuring timely and precise responses to dynamic warehouse challenges. Digital twins can optimize material handling systems, enabling easy planning, deployment, and continuous improvement of mobile robots. Predictive maintenance of equipment minimizes downtime, ensuring an unbroken delivery chain, while AI in quality control guarantees product standards, boosting customer trust and mitigating risks. The rich data gleaned from smart warehouses offer insights for streamlining operations, providing a competitive edge and enabling quick adaptation to market shifts. This transformation is not just about efficiency; it's about redefining the supply chain ecosystem to be more responsive, resilient, and customer-centric.

2ND YEAR ON THE LIST

NANO-FULFILLMENT CENTERS

WHAT IT IS

Nano-fulfillment centers enhance supply chains and logistics by enabling hyperlocal, efficient, and swift last-mile deliveries. These can be small infill sites in the urban center of cities that bring manufacturing and delivery closer to the consumer.

HOW IT WORKS

Automated, localized warehousing facilitates same-day and even quicker delivery to meet the growing demand for speedy e-commerce services. Retail giants like Walmart are already experimenting with this: The company is creating next-generation fulfillment centers that blend robotics, AI, and human expertise to set new standards for delivery speed. These centers aim to reach 95% of the US population with next-day or two-day shipping.

Other startups are focusing on creating technology that can be widely deployed. Nimble specializes in intelligent robotic fulfillment systems designed to efficiently pick, pack, and ship e-commerce orders, focusing on picking as the hardest part of the puzzle. Its technology reduces warehouse space requirements and offers rapid delivery, letting companies outsource their warehousing needs. In a similar vein, KwikShelf empowers Nigerian merchants with efficient inventory storage and order fulfillment. It plans to establish multiple e-commerce fulfillment centers across large Nigerian cities.

However, finding the right place to set up nano-fulfillment centers can be challenging and costly. Mowito operates automated nano-fulfillment centers across Bengaluru, India, where the only human staffers are the delivery personnel who pick up orders. Its AI-driven robotic systems improve order accuracy, reduce operational costs, and enable 24/7 retail store operations.

On a regulatory note, Paris recently implemented a ban on dark stores, which are distribution centers for rapid grocery and household item deliveries. Paris authorities argued that these dark stores violated urban planning laws, categorizing them as warehouses, which are prohibited in residential zones.

WHY IT MATTERS

Nano-fulfillment centers are crucial for e-commerce success as they cater to the modern consumer's demand for rapid delivery. By localizing and automating warehouses with advanced robotics and AI, these centers streamline order processing, reduce errors, and enhance efficiency. They utilize predictive analytics to forecast consumer behavior, strategically stocking items to expedite last-mile delivery. But as regulations evolve, such as the dark store ban in Paris, the industry must navigate new compliance landscapes. One option is to work with local governments overseeing urban centers looking for ways to utilize vacant spaces—dark stores can in fact prevent urban decay. Outsourcing to nano-fulfillment providers offers companies cost-effective warehousing solutions, eliminating the need for large, traditional storage spaces. Upskilling workers to work in these facilities will help companies that face backlash for reducing their dependency on human workers. These centers also represent a strategic evolution in logistics, by prioritizing speed, efficiency, and adaptability to changing market demands.

2ND YEAR ON THE LIST

INTELLIGENT PACKAGING

WHAT IT IS

Intelligent packaging, equipped with real-time monitoring and quality assessment capabilities, is necessary for reducing food waste, maintaining product freshness, and optimizing environmental benefits.

HOW IT WORKS

Clarkson University's biosensors lab has devised a food degradation sensor that enhances intelligent packaging. Discreetly placed within the packaging, the sensor changes color when food begins to spoil, minimizing the risk of throwing away food prematurely. The University of Genoa's Department of Chemistry has similarly pioneered a smart packaging technology capable of detecting amines, compounds that signify protein degradation in meat, fish, and dairy. As amines accumulate during degradation, the packaging undergoes a noticeable color change, serving as an intuitive indicator of product quality. And the UK-based company "It's Fresh!" focuses on extending the shelf life of fresh fruits and vegetables by controlling ethylene levels in the local environment, which is a key factor influencing ripening and spoilage. Recently, Nestle announced its research in using haptic feedback in packaging to provide information about its products.

French company Lactips pioneered the development of edible packaging using casein protein derived from milk. While mimicking plastic's flexibility, Lactips' patented film biodegrades within 18 days, demonstrating eco-friendliness and good performance in keeping perishables fresh. Israeli designer Naama Nicotra's NakedPak transforms edible packaging into a culinary art form: Her innovative edible wrappers include spices and dissolve into delectable sauces when heated. Polynatural, based in Chile, addresses carbon emissions with "Shel-Life," a 100% plant-based emulsion coating that preserves fruits and vegetables during transportation. And Austrian startup Speech Code has a novel sound-based packaging solution for the visually impaired. Its users can scan a unique code image to translate it into text or audio format without requiring internet access.

WHY IT MATTERS

Intelligent packaging should be a critical focus for the supply chain, logistics, and manufacturing industries, as it provides real-time data on product conditions, enhancing food safety and minimizing waste. Sensors will continue to advance, offering new warning systems these industries can capitalize on. Companies should start exploring embedded packaging sensors that detect food degradation, ensuring only fresh, high-quality products reach consumers, which will help maintain brand integrity. Edible packaging presents an eco-friendly alternative, by cutting down on waste and environmental impact. While this novel innovation sounds promising, its success depends on consumer socialization. Reusable packaging further supports a circular economy by encouraging repeated use and reducing waste generation. These smart solutions are not just environmentally beneficial; they also bolster consumer trust and engagement through their active participation in sustainability, offering strategic value to businesses looking to innovate and maintain a competitive edge.

2ND YEAR ON THE LIST

AUTONOMOUS COBOTS FOR WAREHOUSING AND DELIVERY

WHAT IT IS

Autonomous cobots—robots that work next to human workers—and other equipment are augmenting the warehouse and delivery spheres with safety and efficiency.

HOW IT WORKS

Autonomous cobot-powered innovations are transforming logistics for efficiency, safety, and sustainability. BionicHIVE brings futuristic efficiency to existing warehouses with its AI-powered robots that can easily traverse shelves. Exotec's Skypod system functions as an automated fleet of robots, workstations, and conveyors: The solution contains 3D movements without the need of complicated infrastructure, operates in varied temperature conditions, and can access any item within two minutes, enabling a human-free environment.

Clevon, in partnership with Lithuanian grocery chain IKI, is pioneering Europe's first fleet of autonomous robot carriers for daily delivery services. In the US, EASE is partnering with the Ohio Department of Transportation and DriveOhio to deploy connected and automated trucks on revenue-generating routes. Kratos is also extending its platooning technology for self-driving trucks to the Ohio-Indiana region. This technology enables human-operated lead vehicles to be followed and mimicked by unoccupied follower vehicles.

Drones can provide rapid, precise, and efficient transportation while reducing environmental impact. Walmart is expanding its drone delivery in Dallas-Fort Worth through its partnership with Wing. Going beyond drones, MightyFly manufactures and operates long-range autonomous cargo aircraft that enable same-day deliveries with a payload capacity of 500 pounds, a 600-mile range, and speeds of 150 mph.

In enhanced robots, CaPow is providing autonomous and mobile, perpetual cobots, ensuring 100% fleet utilization by eliminating charging downtime. Apptronik unveiled Apollo, a humanoid robot, which features advanced force control architecture for safe interaction with humans. And Agility Robotics announced that its RoboFab facility will pioneer mass-producing humanoid robots, offering greater flexibility and versatility compared to current industrial robots.

WHY IT MATTERS

Autonomous cobots are revolutionizing supply chains by enhancing warehouse operations with their adaptability, safety, and efficiency. They're capable of working alongside humans and seamlessly integrate into current layouts. Advanced technologies are evolving warehouses into human-free zones, increasing efficiency and operational speed. Drones complement these efforts with their swift, precise, and sustainable delivery methods. Humanoid robots with sophisticated force control are stepping in, safely collaborating with human workers for tasks like unloading and picking, bolstering various industries. With their ability to handle repetitive duties, cobots free up human staff for complex tasks, while their embedded sensors offer vital real-time data, making them key to strategic decision-making. Their advanced safety features prevent accidents, ensuring a harmonious human-robot coexistence. Multifunctional, they manage inventory, quality control, and maintenance, proving indispensable to modern logistics. Despite the initial investment, the long-term savings on labor and increased efficiency solidify cobots as a strategic asset for the industry's future.

SCENARIOS

The Chroma Information System

By 2030, the world has embraced the Chroma Information System, a groundbreaking innovation in smart packaging that ended the era of uncertainty in food and medicine quality, giving rise to an unprecedented level of consumer safety and confidence. Every consumable product—from the freshest loaves of bread to the most critical heart medication—is encased in this intelligent packaging, which is equipped with micro-sensors powerful enough to detect the slightest change in the product's integrity. These sensors actively monitor the molecular composition to ensure that the contents remain within the optimal range for human consumption. Each package syncs to the purchaser's wearable device, which holds their personal health and safety data. This harmonious interaction between packaging and personal tech is the cornerstone of consumer safety. The labels now act as an information display. With a simple tap, customers can see how much longer they have to eat the food or if they should get a refill on their prescription. The labels also change colors when the sensors detect a deviation—be it spoilage or a mismatch with the buyer's health profile. When the packaging's exterior, normally vibrant and inviting, morphs into a universal shade of brown—a color specifically engineered to be perceived across the spectrum of color vision—it indicates that it is time to either recycle or compost the goods.

This color change is not just a warning; it initiates an automatic return process. As soon as the product is set down, smart surfaces in homes and stores process the Chroma data and activate a return mechanism. Drones or automated systems retrieve the item, ensuring that it never reaches the consumer's cart or cupboard. The Chroma Information System has rewritten the narrative of consumer safety, where transparency is not just about what lies within but also about taking immediate action when standards are not met.

SCENARIOS

Perpetual Motion Manufacturing

As dawn breaks over the horizon in 2029, a fleet of autonomous trucks are seen roving the highways. These are no ordinary vehicles; they are the pulsing arteries of the world's supply chain, the pioneers of a logistic revolution—they are Platooning Pioneers. Each truck is an autonomous powerhouse, fitted with state-of-the-art additive manufacturing plants, their cargo bays printing orders for toothbrushes, cutlery, glasses, bowls, and wearable cases in real time. The smart highway allows the platoon to be monitored by an intricate network of sensors, relaying information back to the AI command center that calculates every move with precision. There is no need for stops; the platoon is a rolling fortress of productivity, a never-ending loop of delivery and manufacturing. Above, a swarm of drones buzzes like worker bees, each one departing from its respective truck with a package. They scatter across the landscape, their flight paths choreographed by algorithms, ensuring that every product reaches its destination on time. The Platooning Pioneers company offers services that slash delivery times, reduce inventory costs, and minimize waste. This is the epitome of just-in-time manufacturing, a system where the supply chain is not just a route but a mobile assembly line. The Platooning Pioneers have set the stage for an era where roads are no longer mere paths but dynamic streams of creation and distribution.

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ENTERTAINMENT

TABLE OF CONTENTS

TOP HEADLINES

Technology has stepped into the limelight and forced its examination, possibly paving the way towards defining a responsible usage.

01 AI Enters Hollywood Contracts

Hollywood's major labor unions—the DGA, SAG-AFTRA, and the WGA—all added some AI restrictions into their contracts, the first steps to creating regulatory certainty for usage of the tech.

02 Tightening the Belt

As streaming becomes less profitable, production costs rise because of new guild contracts, and box offices continue to underperform, companies are instituting frugality measures such as layoffs.

03 AI Is Making Movies

While still in its infancy, generative AI has graduated to making moving images.

04 Touring Sets New Records

Taylor Swift and Beyoncé set new records in every way, and with more options than ever to view live performances, the artists exponentially increased their earning potentials.

05 Reducing the Environmental Footprint

Sustainability is entering all aspects of entertainment, ranging from movie production processes to amusement park business practices and themes of artistic exploration.

STATE OF PLAY

AI is infiltrating all aspects of the creative process, promising to make it leaner in an effort to increase profitability.

From May 2, 2023 (the start of the Writers Guild strike) to November 9, 2023 (when the tentative agreement with SAG-AFTRA was announced), studios and creators didn't produce any work as they grappled with how AI could be leveraged fairly in the creative process. The result was new contracts that made significant strides toward protecting guild members, even though much of the language is vague—a necessity, as the potential of AI is just being explored. The results provide much-needed guardrails to enable sustainable usage of artificial intelligence, an example other industries will emulate.

Generative AI has continued to democratize creativity, and we've seen both short films developed using text-to-video and a YouTube-DeepMind AI partnership that creates songs in the style of any artist. However, this democratization tends to create an overabundance of creators and content that could further fragment the audience and contribute to content fatigue.

Sustainability is now a main consideration: Film sets have sustainability advisors, tours and theme parks run on renewables, and streamers are reducing their digital emissions. Advances in holography and haptics enable a range of "secondary" experiences, too. These aren't meant to replace the live event experience, but rather offer additional options at different price points (and varying environmental impact), opening up fresh ways of monetization.

KEY EVENTS

MAY 18, 2023

Galactic Starcruiser closure announced
Disney closes its "Star Wars" hotel due to poor performance, dampening development of elaborate immersions.

JUNE 2, 2023

AI-generated short premieres
Every shot of the film is generated by Dall-E.

NOVEMBER 9, 2023

SAG-AFTRA agreement proposed
After the WGA, the end of the actors' union strike enabled the industry to get back to work.

JUNE 2, 2023

Coldplay's sustainable touring
The band announces their tour's reduced emissions and waste. It also runs on renewable energies.

OCTOBER 27, 2023

AI celebrity twin
K-pop star Mark Tuan connects his digital twin with ChatGPT so fans can converse with him 24/7.

LIKELY NEAR TERM DEVELOPMENTS

TIGHTENING THE BELT

After the golden age of content, all signs are now pointing toward efficiency measures. Fears of a recession, inflation, a widening wealth gap, and geopolitical instability have many people holding on to their financial resources. And that's especially true in the entertainment industry, as problems with the streaming business model, increased production costs based on the new union contracts, and fractured audiences create an environment of extreme frugality. Technology looks like a knight in shining armor, promising to increase production speeds and reduce costs without decreasing quality—if it is incorporated ethically and sustainably. After the unions' negotiated contractual guardrails, those goals may be easier to achieve.

Lower Production Budgets

As studios work toward making their streaming services profitable, new lean processes will walk the line between providing enough content variety to avoid subscription fall-off and actually making money.

Sustainability Practices

Gone are the days when entertainment companies just have to take their direct emissions into account. They'll also have to consider reducing fan and production travel emissions, recycling, and using sustainable materials when planning and executing content.

Overpresent Celebrities

Digital celebrities, both those with human counterparts and those without, allow anytime access for fans but run the risk of eradicating the defining feature of celebrity: scarcity.

Engaging Broader Demographics

The aging population in Europe, Asia, and to a lesser degree the US, requires strategizing about what topics will make people over age 60 tune in. On the other end of the spectrum, Gen Z requires special enticement to watch long instead of short-form content.

Live-ish Experiences

As people have less disposable income, they will seek alternative entertainment options. Local pubs broadcasting a game or smaller, local live venues might be more attractive experiences than stadium concerts.

Copyright Chaos

Microsoft launched its Copilot Copyright Commitment, assuming users' legal copyright risks when using the company's AI Copilot. However, as long as there is no clear regulation, the use of many AI tools will continue to carry substantial legal risk.

11 MACRO SOURCES OF DISRUPTION

Technology | Media & Telecom | Demographics | Environment | Government | Public Health | Education | Geopolitics | Infrastructure | Economy | Wealth Distribution

WHY ENTERTAINMENT TRENDS MATTER TO YOUR ORGANIZATION

Shifting Customer Habits

Changing demographics mean serving audiences with very different budgets, spending habits, and entertainment needs. As audiences become increasingly fractured and content even more abundant, it's crucial to fine-tune offerings and approach storytelling from a world-building perspective with multiple entry points.

New Creative Expressions

Influenced by the gaming experience, consumers engaging with imaginary worlds continue to demand more influence over them. Technology makes this easier by democratizing the necessary tools, but companies need to figure out how to collaborate with the audience without decreasing the quality of the work.

Unexpected Disruptors

Gaming, live events, and social media are Gen Z's favorite forms of entertainment, all of which have strong communal elements. Apparel brands, food and drink companies, and hospitality companies are well-positioned to expand on their traditional offerings and create more immersive worlds that capture that generation's attention.

First Mover Advantage

Artificial intelligence will fundamentally change processes: business-related, administrative, and creative. Companies that embrace changes early on and rethink the way they do business will have the chance to create industry standards that are best for their purposes.

Irrelevance of Originality

The immersive exhibits for artists like Vincent Van Gogh that have sprung up over the past few years might be dismissed by art aficionados, but their huge success shows they hit a nerve. As AI becomes more prevalent in fine art, globally reproducible exhibit experiences might replace the admiration of a singular work.

Access to Personal Data

A decentralized data structure where the user has complete control over who can access personal data and for how long will shift willingness to share information. Entertainment companies will benefit if they consider early how to best utilize the insights they will gain, whether it's within existing or new experiences.

OPPORTUNITIES & THREATS

Threats

The regulatory landscape for new tech, specifically AI and copyright, is still largely unexplored, and the regulations that do exist differ by country. This uncertainty can easily expose a company to significant legal liabilities.

The ease of creation that technology enables needs to be approached with caution. Frequent exposure to a franchise decreases audience interest and quickly leads to an apathetic response.

With digitization comes increased vulnerability to cyberattacks. As personalization becomes more prevalent, companies need to ensure that their customers' data is safe throughout the entire ecosystem of devices they use for the experience.

It's still unclear if streaming is a viable business model, and if technological advances can offset rising production costs. Pressure tests will reveal whether companies can continue to generate a profit in the shifting media landscape.

Interactive entertainment does require a minimum level of digital access, which includes hardware but also connectivity. A product's reach needs to include swaths of the population with limited resources and access.

Opportunities

Collaborations will uncover best practices for integrating new technologies in AI or XR. Joining forces with a niche player in the field is often more sensible, efficient, and less expensive than trying to build capacities in-house.

Both digital interactions and real-life offer opportunities to increase the level of engagement with audiences, and companies can choose to do this within an existing repertoire or with completely new products.

The fragmentation of audiences and desire for local content provide room for diverse voices to tell their stories, but companies should make sure new products that speak to different niches are still authentic to the brand.

Technology lowers the creative industry's barrier to entry—not only for consumers but also for companies. It's never been lower risk to experiment with new, unconventional ways to tell a story and engage audiences.

Using audience data creatively is crucial. How can you let data flow into your development process in fresh ways? How can you build additional trust to gain insights and provide a higher degree of personalization?

INVESTMENTS AND ACTIONS TO CONSIDER

1

Build an international network of collaborators and partners. The increased taste for locally-produced content will require experts that are familiar with not only the creative sensibilities but also the business in the different territories. Technology enables even smaller players to diversify their product offering.

2

Invest in analyzing your environmental footprint. As both ESG standards and consumer sentiment toward sustainability become more demanding for entertainment, it's imperative to have transparency throughout your entire supply chain.

3

Stay current on legal developments—litigation as well as regulation—for new technologies. Make sure to venture beyond topics that are immediately relevant for your company, such as XR or generative AI. Overall or tangential legislation can serve as an impulse driver for topics important to your business.

4

Fine-tune your value proposition on a granular level, and then adjust it for the different audiences you serve without compromising its core. In a world of content overabundance and increasing personalization in every aspect of a consumer's life, each piece of content needs to exactly fit an audience's needs.

5

Investigate thoroughly where crowdsourcing will serve the quality and relevance of your product offering. This type of audience engagement is compelling, especially as it is just emerging, but can easily devalue the product and water down singular visions of creators, instead of enriching storytelling.

6

Ensure you have direct access to your customers so you can market your products to them. The internet will change, and increasingly chatbots will become the new gatekeepers instead of users searching the net. It'll be even more challenging to find content as users stay on a single interface.

CENTRAL THEMES

From Creator to Creative Director

Books, songs, images, presentations, short stories, videos—anything can be created with the touch of a button. While this empowers people who never before had access to creative tools and allows for diverse and fresh voices to be heard, it also shifts how humans use their brains. Editing and directing someone else's output (whether a person's or AI's) is not as laboriously exhausting as birthing the piece of art. That might be fine, but it could also lead to more superficial engagement, decreasing impact and quality of creative endeavors. It also might have a different effect: a resurgent need for in-person and analog activity to be sure of someone's actual capabilities. After all, only if you see someone create work can you confirm that no artificial means were used in the thought process or creative endeavor. Already today, schools are returning to oral exams for that reason, and startup investors are beginning to insist on in-person meetings to determine how clear a founder's thought processes are.

Personalized Content

Personalization of content is happening on two fronts: for a single viewer and for the entire audience of a show or movie. Netflix continues to dabble here, with the recent release of the interactive rom-com "Choose Love," and Genvid released Silent Hill, a massive interactive live event where the storyline is driven by the audience voting on how different characters should behave. But significant developments are also happening outside the industry, where increasingly sophisticated sensors in our smart devices can measure our biomarkers and AI can detect our mental and emotional states based on that data—in real time. Eventually, a more streamlined version of personalized content won't require conscious interaction with the viewer but will instead be synthesized by an AI based on our personal data. For both consumers and content producers, this will create unlimited opportunity to engage with established or new franchises, as the story will be different every time.

The Industry Goes Green

Voluntary or not, sustainability is increasingly a consideration in entertainment. Large movie productions hire sustainability consultants, theme parks are optimizing their energy usage and participating in the circular economy, and in the art world, exploration of environmental themes has become more common. In the performance industry, Coldplay's "Music of the Spheres" tour raised the bar when it comes to holistic practices: it notched milestones including a 47% reduction in direct CO_2 emissions and planting 5 million trees, one for each concertgoer. In TV, the industry started addressing and minimizing the emissions connected to streaming. As the effects of climate change further escalate, consumers will demand sustainable practices from all their favorite brands, including their beloved celebrities. This makes it all the more surprising that neither of 2023's biggest tours—from Taylor Swift and Beyoncé—made any official announcement about their sustainability efforts.

CENTRAL THEMES

Immersive Experiences

Immersive entertainment is becoming more common, with Las Vegas venue Sphere setting the standard. Haptic seats vibrate and shake to convey a more realistic sense of what's happening on screen, scents are channeled into the room, and temperature is adjusted to create a new level of immersion into imaginary worlds. While the gaming and localized entertainment industries are much further along with helping their audience feel as if they're living in an alternative reality, these efforts are starting to bleed into traditional viewing experiences. Beyond Sphere, traditional movie theaters have integrated haptic devices; these offer a great differentiator to at-home entertainment and represent an attempt to get people back into cinemas, at least until the technology can be scaled for in-home use. As these new types of scores (olfactory, sensing) are added to productions, studios will need creative talent that can design and create cohesive sense layers for an entire show or movie, just as they do now for music or sound.

Secondary Live Experiences

With the restrictions of the pandemic still fresh, people are flocking to communally experience live performances. Last year, Taylor Swift and Beyoncé's mega tours broke every existing record, and they promise to continue to draw millions of people in 2024. Both stars also revived another form of entertainment: the concert film. Released first while she was still on tour, Swift's film was a huge success, opening up secondary ways for fans to experience live entertainment. The movie's audiences were (almost) as engaged as those who saw her performances in person, confirming the potential for deep emotional engagement even for those more removed types of experiences. As technologies like holograms and extended reality evolve with the necessary supporting infrastructure such as 5G and 6G, it's easy to imagine myriad ways that a performance can be enjoyed depending on personal budgets and level of enthusiasm.

Splintering of Content

Audiences have been becoming more and more fragmented for years, making it difficult for stories (or actors for that matter) to gain global momentum. Now, audiences are increasingly favoring locally-produced content that stars local actors and caters to local sensibilities and senses of humor. And studios, both traditional ones such as Warner Bros. and Paramount and streaming platforms like Netflix and Amazon, are adjusting their strategies: All of them shifted toward country or regional-specific content production. If an idea works, it might get recreated for a different country, as was the case with Netflix's French series "Call My Agent!," which was reshot in the UK as "Ten Percent." While this strategy creates more content and keeps people employed, smaller target audiences also means smaller budgets and more reliance on technology to increase efficiency. It'll also prevent the habit of relying on global talent to carry tentpole productions, currently the cornerstone of every major studio's revenue projection.

ONES TO WATCH

Ke Li, Ph.D. student at Cornell University, for developing a wearable that creates a digital avatar based on facial expressions captured through sonar.

Hyunchul Lim, Ph.D. student at Cornell University, for developing a wrist camera that can construct 3D models of the body.

Sven Bliedung von der Heide, CEO of Volucap, for working on a completely portable volumetric video stage and pushing the boundaries of the medium.

Jacob Navok, CEO of Genvid Technologies, for making progress on interactive audience streaming and creating a new genre of entertainment with massive interactive live events.

Tod Machover, director of MIT's Opera of the Future, for his work on city symphonies, which create soundscapes of metropolitan areas in collaboration with their residents.

Keri Kilty, founder of Authentify Art, for developing a unique Internet of Things tag to verify proof of presence and tracking information of art pieces.

Pär Almqvist, co-founder of Tracklib, for simplifying sampling for musicians while providing transparency in regards to copyright ownership.

Thomas Villepoux, storyverse designer at Digital Rise, for creating the VR series "Jailbirds—The Eye of the Artist," showcasing the possibilities of this storytelling form.

Davy and Kristin McGuire, founders of Studio McGuire and mixed reality artists, for seamlessly merging analog and digital in their Dracula pop-up book.

Eloise Singer, CEO at Singer Studios, for intriguingly combining education and entertainment with her interactive VR experience about Bertha Benz's role in developing the first automobile.

Dennis Lisk, Max Sacker, and **Ioulia Isserlis,** co-founders of Proof of Taste, enabling anyone to DJ in front of a virtual crowd in a photorealistic environment.

Zeena Qureshi, co-founder of Sonantic, for her use of artificial intelligence to create realistic voices, such as Val Kilmer's voice in "Top Gun: Maverick."

Phil Chen, founding partner at Race Capital, for his leadership at HTC Vive, which created the VR theater project "Light the Night: Redhat Killer" based on the namesake Taiwanese series.

Alan Cowen, founder and CEO of Hume AI, for working on AI that can detect and understand human emotion.

Akira Asano, director at Aerial Burton, for creating a holographic projector that uses plasma laser to create images without needing a surface for bouncing light .

Stephen Parker, creative director at Waymark, for creating the short film "The Frost" with every shot generated by GenAI Dall-E.

Scott Mann, co-founder of Flawless AI, for facilitating the use of AI in the filmmaking process, specifically synchronizing the actors' mouths to new lines of dialogue or dubbing.

Tonia Samsonova, founder of Exactly.ai, for allowing artists to train an AI model on their own images so that it can apply the style to new creative works.

Marc Carey, CEO and co-founder of Evolution Music, for promoting sustainability in the music industry by creating a bioplastic LP.

Dom Robinson, founder of Greening of Streaming, for bringing transparency to the environmental impact of the industry and initiating change.
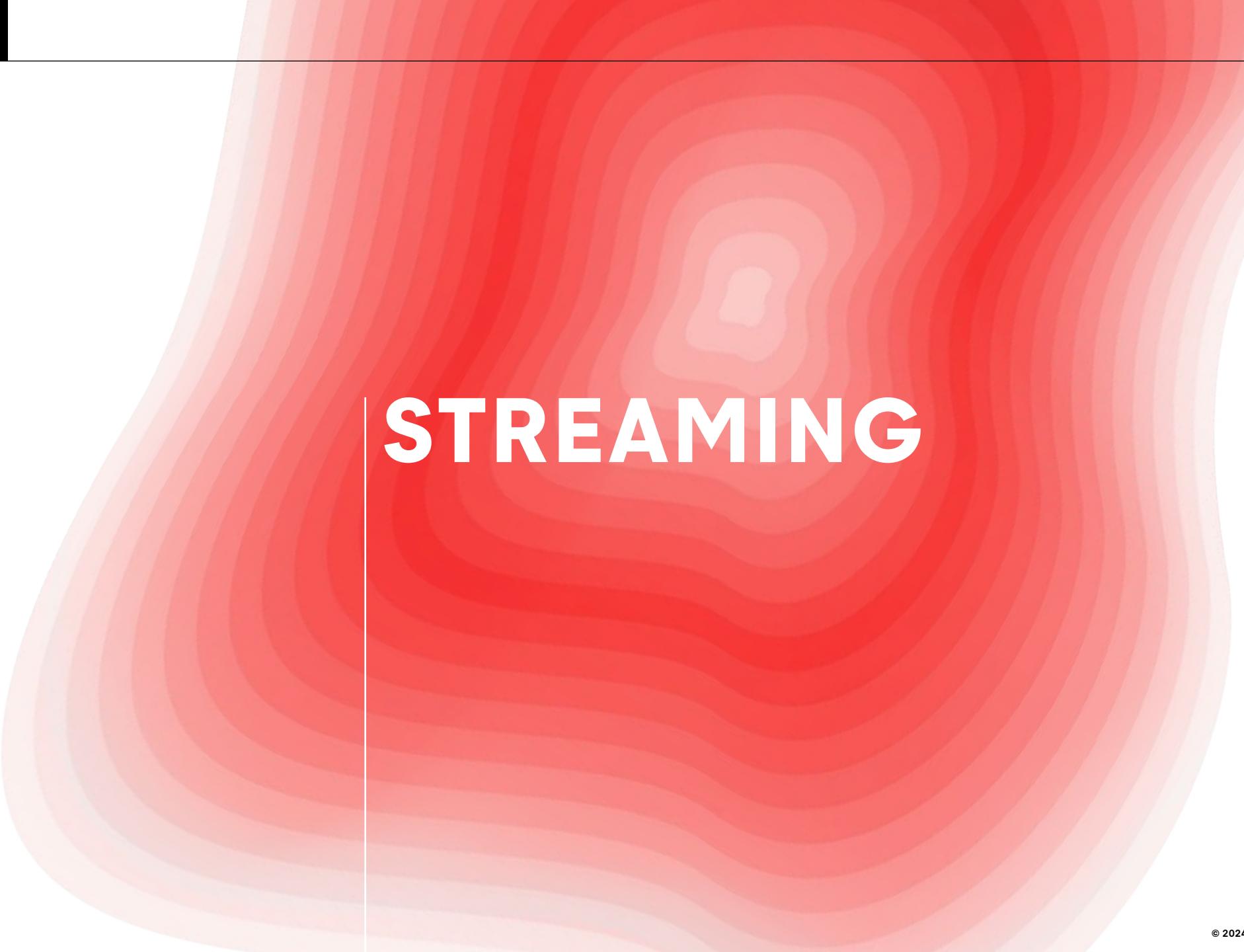
Steve Zhao, founder and CEO of Sandbox VR, for creating immersive local VR entertainment, the latest creation being an adaptation of Netflix's "Squid Game."

Patrick Johnson, CEO and founder of Rock Paper Reality, for bringing augmented reality to San Francisco's Japantown with custom digital origami artwork.

Paul France, founder and CEO of Existent, for developing a platform that allows for actions in VR to affect the real world and vice versa.

Nick Fellingham, founder and CEO of Condense, for building a platform that easily captures live performances and streams them into a virtual reality in real time.

STREAMING

THE NEW INFLUENCER ECONOMY

WHAT IT IS

The influencer economy—driven by digital creators producing content to generate revenue for self-profit, brands, advertisers, and platforms—is estimated to hit over $21 billion in 2023. And it will only continue to grow, thanks to the expanding network of startups supporting the new class of entrepreneurs who thrive on social media.

HOW IT WORKS

Platforms are constantly coming up with new ways to attract valuable influencers. Last June, TikTok introduced subscriber-only videos—a perk exclusively available to creators with over 1,000 followers, designed to strengthen ties between influencers and their fans. And in September, it launched TikTok Shop, which grants brands and creators the ability to sell directly through shoppable content on the TikTok app. In addition, Creative Juice has pledged to infuse $50 million into its Juice Funds, which allows deep-pocketed influencers to invest in up-and-coming creatives. The fintech company's new Refresh product will showcase its take on the catalog licensing model pioneered by creator-growth companies like Jellysmack and Spotter.

"Synthetic influencers," anthropomorphic entities generated using AI, are also making waves: In 2022, Lu do Magalu—the face of Brazilian retailer Magazine Luiza and the world's most popular virtual influencer on Instagram—raked in over $16 million from sponsorship deals with brands like Adidas and MAC Cosmetics. Synthetic influencer creator Superplastic recently raised $20 million led by Amazon's Alexa Fund in a deal that includes an animated series. The startup, launched by Kidrobot founder Paul Budnitz, plans to draw strategic backers like Google Ventures, Galaxy Digital, and Sony Japan to develop more character-based products across multiple platforms, including video games and social networks.

WHY IT MATTERS

Global ad spending on influencer marketing is projected to exceed $32 billion in 2024. And with no shortage of digital influencers in sight, the influencer economy will soon overtake conventional marketing and advertising channels. The emergence of virtual influencers adds a whole new layer of complexity to the evolving class of tastemakers, who are already struggling to stand out in an oversaturated space. But AI-generated stars, which are becoming increasingly easy to produce and maintain, threaten to undermine the power and attractiveness of their human counterparts. Instead of paying a real-life influencer thousands of dollars per post to promote their products, brands may choose to collaborate with a computer-generated persona that's more flexible and affordable. After all, virtual ambassadors carry a lower risk of damaging a brand's reputation, since unlike humans, they're not prone to emotional outbursts or bad behavior. The rise of synthetic influencers—such as Meta's digital doppelgangers of real influencers TikTok tastemaker Charli D'Amelio and YouTube star MrBeast—might also worsen the mental health of social media influencers, many of whom reportedly suffer from paranoia, angst, and low self-esteem due to constant pressure and scrutiny. Their inability to achieve the same level of perfection as their AI-made rivals might result in even more anxiety and depression.

DECENTRALIZED CREATIVE COLLABORATIVE

WHAT IT IS

The growing demand for content has led to many new ways to produce it virtually, fueled by a global talent pool of creatives continually craving fresh ways to collaborate. Extended reality could enhance the field of decentralized creative collaboration, leading to more immersive engagements and allowing companies to even more accurately recreate in-person experiences for remote participants.

HOW IT WORKS

CTERA Cloud Streaming allows creatives to seamlessly work together in real time using popular editing suites like Apple Final Cut Pro, Black Magic Design DaVinci Resolve, and Adobe Premiere Pro. Meanwhile, in the music realm, Audiomovers added MIDI streaming to its Listento software suite, allowing Listento Pro subscribers to easily transmit real-time MIDI data from any digital audio station over the internet. That means a music producer can capture a faraway musician's live performance in real time and then immediately incorporate elements like additional instruments to enhance the recording. Last April, Adobe expanded its Frame.io collaboration platform to accommodate photos and PDFs. The offering allows users to capture, edit, review, and approve content through a single hub, drastically improving workflow. Camera-to-cloud integration lets creatives upload and store their media online and immediately access it from anywhere. Atomos, which produces recording monitors, has loaded its Ninja V and Ninja V+ models with the C2C technology, inviting its users to enjoy the feature through Atomos Connect.

WHY IT MATTERS

Improving ways for creators to collaborate remotely makes content faster and less expensive to produce, and can potentially boost output quality and value. C2C technology simplifies immediate file sharing, eliminating the need to ship memory cards and hard drives and minimizing the risk of data loss or damage. This democratization of creative tools has spurred the expansion of talent pools internationally, enabling creators from opposite ends of the Earth to work simultaneously in real time. In turn, this phenomenon could unite a more diverse mix of voices and perspectives, ultimately leading to a more colorful showcase of stories and ideas. The maturation of audiovisual and haptic hardware will accelerate the adoption of these practices, along with the proliferation of next-gen connectivity (5G and beyond), which will allow for near-zero-lag live collaboration and let more creators simultaneously use data- and compute-intensive creative platforms. It could even spur the emergence of new forms of art and content (think: works produced by artists' collectives at the scale of massive multiplayer online role-playing game user bases).

IMMERSIVE NARRATIVES

WHAT IT IS

As our entertainment devices become more advanced, consumers are increasingly seeking out more engaging content that they can experience with multiple senses. New strides in volumetric video capture, spatial audio, and haptics allow audiences to see, hear, and feel the action like never before, turning passive spectators into active characters in a story.

HOW IT WORKS

Around the world, entertainment venues are experimenting with immersive shows. At the Las Vegas Sphere, the iconic rock band U2's performances unfold in a high-tech dome featuring haptics in 10,000 seats and a wraparound LED screen enhanced with 4D effects, including wind and scent. At Universal Studios Orlando, the "Bourne Stuntacular"—a live show based on the Bourne films, set in a theater with a 130-foot-wide LED screen and automated interactive set pieces—delivers in-your-face action including high-speed chases, intense fighting scenes, and a thrilling rooftop escape. And the "Tornado Chasers" attraction at France's Futuroscope offers a whirlwind experience comprising on-stage action and a 360-degree screen, with the audience seated on a circular platform that rises, tilts, and turns. Similarly, the Attraktion! Dome Ride Theater at SeaWorld Abu Dhabi boasts a dynamic seating ring alongside a 56-foot-wide LED sphere providing an uninterrupted 360-degree view. Companies are also finding ways to make video-game narratives more immersive: While playing "Assassin's Creed Mirage," gamers wearing the OWO vest can experience sensations exclusive to the new release. At IFA 2023, French company Actronika debuted similar haptic gear that's capable of simulating the feeling of getting hit by a fireball or standing in a rainstorm. Showcasing less tech-centric (but equally immersive) spaces, the exhibition "Tim Burton's Labyrinth" takes visitors on a multisensory journey through the filmmaker's whimsical world—a tangle of walkable mazes with over 300 routes to explore, peppered with strange sounds, tactile touches, and optical illusions.

WHY IT MATTERS

As consumers' appetite for multisensory experiences increases, creatives will have to push the envelope on designing one-of-a-kind engagements that showcase olfactory, tactile, and spatial elements to keep up. Beamform technology—which allows two people sitting five feet apart to hear different sounds or languages without headphones, creating a sensational experience that's unique to each guest—unlocks a whole new level of event customization and could bring more diverse audiences together under the same roof. And the "lickable TV," which is covered with a hygienic film that can be sprayed with various flavors, offers onlookers the chance to taste the food shown on the screen. (If commercialized, such an invention could enable distance learning for cooks, tasting games, and the ability to explore restaurant menus from across the globe within the comfort of your own home.) Meanwhile, interactive entertainment will overtake content meant for passive consumption, ultimately leaving a deeper imprint. And the practice of converging multiple media types into one experience—like a concert within a video game—will create new revenue streams for brands, advertisers, and performers. Entertainment venues will increasingly depend on haptics and enhanced audio, driving up the price of admission to events and performances across the board.

2ND YEAR ON THE LIST

PERSONALIZED CONTENT

WHAT IT IS

With the emergence of more flexible forms of storytelling, audiences are no longer limited to a single journey. Viewers are invited to influence how the narrative unfolds, and AI-assisted writing can customize plotlines based on a user's viewing history, browsing habits, and favorite digital publications.

HOW IT WORKS

Netflix's 2018 series "Black Mirror: Bandersnatch" presented viewers with a dizzying array of choices and possibilities, encouraging them to engage with the film more than once. Similarly, the streaming service's first interactive rom-com, "Choose Love," let audiences pick who the protagonist falls for, with six potential endings. In 2022, Amazon announced Create with Alexa, a kid-friendly AI tool that will craft a short story with just a few words. The company claims the outcome will be different every time, even if a child picks the same exact prompts. In gaming, a new feature from NVIDIA gives players the ability to speak directly to a video game character and receive an immediate response, so they become part of the story themselves. Though personalization is mostly rooted in viewers actively making choices as the story progresses, AI algorithms could curate content for users based on how they say they feel. For instance, a verbal prompt such as "show me a movie that will make me laugh" would automatically generate a list of comedic titles to choose from, tailored to an individual's past viewing history. Technology could also evolve to the point where users are linking their biometrics to streaming services using smartwatch sensors, which would receive information about their mental and emotional states. Then media platforms could determine the direction of a narrative based on viewers' reactions to each scene (as indicated by their perspiration level, body temperature, and heart rate)—without requiring their active intervention.

WHY IT MATTERS

Interactive storytelling stands to boost customer loyalty and engagement, as well as allowing content creators and streaming services to learn more about their audiences and use that data to tailor ads. Micro-fandoms surrounding different versions of the same title could emerge, while die-hard fans might band together to figure out every possible combination of events and determine the best path to take. Interactive content could also help recapture users who are tired of conventional storytelling. Children's programming might benefit from flexible formats the most: Kids tend to have shorter attention spans, so they get bored of traditional content easily—and they have the time to engage with shows, unlike many adults who like to multitask while watching television and don't have the bandwidth to consistently interact. One potential downside is that these multilinear narratives may make it difficult for audiences to properly recognize and discuss important societal topics that the content aims to bring to light.

MASSIVE INTERACTIVE LIVE EVENTS

WHAT IT IS

Combining the reach of broadcast TV and the interactivity of video games, massive interactive live events (MILEs) invite audiences to follow a plotline that unfolds over several weeks, encouraging them to interact with a livestream to impact the action. The cloud-powered format is meant to entertain both passive viewers and actively engaged participants in real time.

HOW IT WORKS

The first-ever MILE, an online series called "Rival Peak," emulated a reality TV show starring 12 AI-generated competitors. Over 12 weeks in 2021, the show received 200 million engagements on Facebook. More recently, DJ2 Entertainment (one of the companies behind the pioneering production), announced "Silent Hill: Ascension," which follows multiple main characters tormented by monsters around the globe. Genvid Technologies has raised $113 million to develop MILEs and has announced two upcoming projects: "Borderlands EchoVision Live," where viewers will sway the misadventures of eight tourists who find themselves in trouble after setting off on a safari, and "DC Heroes United," where fans will influence the interactions of their favorite superheroes and help form a new Justice League. Genvid's latest MILE concept, "Project Raven," imagines users who will not only be empowered to decide the fate of humans hunted by zombies but also create characters they can send straight into the action. The company is also exploring the idea of community building through MILEs, where participants of all ages can enter a livestreamed 3D space and engage with one another within a set time frame. Users would move freely within the digital realm and see the paths others have followed before them.

WHY IT MATTERS

The next generation of MILEs will call for a deeper collaboration between audience members at a much greater scale, inviting millions all over the world to act concurrently to control a storyline. Micro fandoms championing every possible ending may emerge, spurring the creation of multiple digital communities, each dedicated to engendering a specific outcome. While "Rival Peak" encouraged fans to work together to earn points, the ability of viewers to create characters in "Project Raven" marks a new milestone in two-way storytelling, blurring the boundaries between the series' spectators and creators. As participants become more involved in developing a MILE, they could be rewarded for their characters' performance, with prizes delivered in the form of exclusive digital perks, small royalties, or even fractional ownership of the series. Successful MILEs could be translated into different forms of media, from colorful graphic novels to complex VR experiences.

DIGITAL CELEBRITIES

WHAT IT IS

Virtual stars never complain or get into trouble—plus, they work for free and are always available. That makes them much easier to deal with—not to mention, more lucrative—than human entertainers, creating a huge point of contention in the industry. Consequently, one of the main goals of last year's SAG-AFTRA strike was to stop AI from replacing actors on set.

HOW IT WORKS

You may have already heard a virtual star on the radio or streaming music. Live 95.5, a radio station in Portland, Oregon, sometimes broadcasts a synthetic version of its midday host using Futuri Media's RadioGPT—an AI-powered tool using GPT-4 to generate a script based on trending news. K-pop star Mark Tuan was the first celebrity to link his digital twin to a large language model, allowing fans to interact with him 24/7. And Hume, creator of "metastar" Angelbaby, raised $11.7 million to fund the creation of more virtual music artists. But not all of these virtual stars are authorized. Last year, a song featuring unauthorized deepfakes of Drake and The Weeknd's voices, called "Heart on my Sleeve," went viral. Tom Hanks took to Instagram to warn his fans about a dental plan ad that showcased an unsanctioned AI version of himself. And Warner Music signed a record deal with digital pop singer and Instagram influencer Noonoouri, whose voice was created using generative AI.

While some musicians distance themselves from unapproved digital creations, others are embracing the new trend, urging fans to create content featuring their digital twins. One example is artist Holly Herndon, who created a site that allows anyone to produce deepfake songs using her voice. Similarly, Singaporean actress Jamie Yeo granted fintech company Hugosave permission to use her digital clone to sell its content, while soccer star Lionel Messi gave PepsiCo the green light to use his deepfake to promote Lay's potato chips. Last October, Meta unveiled a roster of digital doppelgängers inspired by real-life celebrities, from anime superfan Tamika (played by Naomi Osaka) to "big sis" Billie (modeled after Kendall Jenner).

WHY IT MATTERS

As deepfake technology advances, it becomes harder to determine the authenticity of media, leaving celebrities more vulnerable to having their likenesses imitated and manipulated without their consent. Digital twins raise a lot of thorny questions about ethics and the mental health implications of giving users access to lifelike digital versions of favorite celebrities, which might lead to unhealthy one-sided relationships in social media and the metaverse. On the positive side, digital twins unlock many new opportunities for engagement. Fans can communicate with real-life stars in their own language and interact with their virtual versions at different ages, making celebrities seem relatable to a broader audience.

Virtual stars could eventually outpace real-life performers in terms of earnings and reach. After all, AI creations—which are increasingly becoming cheaper to produce—demand no pay and require minimal upkeep. (Though this will likely not be the case for digital twins of human celebrities, who will eventually be compensated once proper legislation is put in place.) Digital celebrities can also be scaled and adjusted to suit any time or space, giving them an edge over flesh-and-blood entertainers. With human celebrities increasingly willing to relinquish their full image rights to AI companies hoping to capitalize on their likeness, the media might soon be overrun with licensed deepfakes. Deceased creators could produce new works posthumously through their digital twins, which could be programmed to behave exactly as the creators did while alive.

AI ASSISTED CREATIVITY

WHAT IT IS

Artists are increasingly relying on artificial intelligence not only to improve their creative processes and come up with project ideas but also to generate complete works—and even direct productions—with very little guidance. This begs the question: Does it matter whether a piece of art is created by a human or a machine?

HOW IT WORKS

Artificial intelligence tools are already being utilized in video production. Synthesia employs natural language processing and machine learning algorithms to produce high-quality videos from text without any actors, mics, or cameras. Similarly, Synthesys' technology allows you to pick a "Humatar" and feed a script for it to read in one of 140+ languages. And new tools such as InVideo and Veed. io enable users to create videos complete with a script and voice-overs and then edit them using simple text prompts to delete scenes, change accents, and more. Last year, 28 Squared Studios and Moon Ventures released "The Safe Zone," a seven-minute film fully written and directed by artificial intelligence. The producers—who generated an entire storyboard using Dall-E 2—consulted ChatGPT on every stage of the filmmaking process, from prop suggestions and lighting requirements to camera positioning and costume design. In the music realm, AudioCipher's text-to-midi plugin empowers creatives to turn words into melodies and progressions; Soundraw lets creators choose a mood, genre, and length to compose a track; Chirp turns lyrics into 20-second song sketches; and WarpSound supports GPT-4 text-to-music generation for live YouTube and Twitch streams.

WHY IT MATTERS

With the help of AI, nearly anyone can create a masterful work with minimal effort. Trained artists are forced to compete with computer-savvy creators who can produce comparable content in a fraction of the time, despite lacking an artistic eye or a musical ear. And creatives are being pressed to develop new skills in order to stay relevant, transitioning into a hands-off role that calls for less ideating and more supervising. AI is blurring the lines between the conventional and the unorthodox, diluting the art marketplace and making it more difficult for consumers to navigate. Are humans going to be more or less likely to go see a painting at a museum if it's produced with a few lines of text in a matter of seconds? How will creatives' growing reliance on AI tools impact the quality of content they generate? Should AI-assisted art be valued the same as their classically made contemporaries? And is the proliferation of AI works a threat to traditional artists? In the wake of the 148-day Writers Guild of America strike that paralyzed Hollywood, it's easy to wonder whether AI stands to diminish the voices and power of human creatives, disabling them from fighting for better work conditions in the future.

4TH YEAR ON THE LIST

AI GENERATED VOICE ACTING

WHAT IT IS

AI makes it possible to take a film's dialogue and dub it in multiple languages using re-creations of the actors' voices. It can also synchronize the translated speech with the performer's mouth movements, making it appear even more realistic.

HOW IT WORKS

Co-founded by movie director Scott Mann, Flawless AI provides AI tools to filmmakers and entertainment companies. The company is partnering with US seller and distributor XYZ Films and UK producer Tea Shop Productions to obtain the rights to foreign-language films. The company's proprietary TrueSync technology—which was used in Mann's "Fall" to cover more than 30 F-bombs that impacted the film's initial rating—will create lip-synched versions of the acquired titles and convert them to English, starting with Crazy Pictures' sci-fi adventure film "UFO Sweden." Netflix doc "The Andy Warhol Diaries" showcased a synthetic version of the late artist's voice produced by Resemble AI's voice generator, which empowers users to create human-like voiceovers in seconds. And AI startup Papercup is collaborating with Fremantle to localize the British TV production studio's catalog of talent shows for Middle Eastern audiences, with technology that automatically translates and dubs video content into Arabic. Indie film studio FilmRoj's Polish psychological thriller "Swarm" features AI dubbing by Deepdub. The Tel Aviv company's Deepdub GO makes professional-level dubbing available for all content types, and allows creators to use their own voice to guide intonation. Meanwhile, Klleon's patented technology can generate lip movements while maintaining the same voice and facial expressions with just one photo and a 30-second recording.

WHY IT MATTERS

As viewers' tastes become more diverse, streamers continue to ramp up their efforts abroad, churning out endless content featuring international casts and storylines. Simplifying the localization of media, AI dubbing has greatly extended the reach of cinematic productions, allowing distributors to target different audiences all over the world. Movie dialogues can also be tailored to suit various ages, further broadening their appeal. The new capability stands to drastically decrease production costs and unlock new revenue opportunities for producers and distributors. Actors could also benefit from the AI-powered technology, since it would increase their availability to take on more work by reducing the need for reshoots. But it might be bad news for Francesco Pannofino—the official Italian voice for George Clooney and Denzel Washington—and other local voice artists who could foreseeably lose their jobs to AI-powered tools. Audiences might protest the practice of having actors seemingly speak languages they're not fluent in, the same way public outcry arises when performers portray different races and cultures.

5TH YEAR ON THE LIST

AUTOMATED CONTENT PRODUCTION

WHAT IT IS

AI is providing more efficient ways to streamline workflows and processes, enabling companies to not only scale their corporate communications and marketing efforts but also crank out fresh material at lightning speed with just a few text prompts and clicks. And with more solutions being bundled, automating content is bound to become even more affordable.

HOW IT WORKS

Emarsys provides an omnichannel automation platform with AI tools and insights for marketers to quickly pin-point priority customer segments and launch integrated campaigns across multiple channels. Similarly, Zapier lets users create customized automated workflows by having them simply outline their needs in writing. The company's AI tools then crank out personalized no-code automation apps and dashboards. And Axios HQ offers AI-powered software that helps large organizations better manage their internal communications. Powered by a data-driven formula, the company's Smart Brevity AI tool crafts and delivers messages designed to keep stakeholders well informed and aligned. Aug X's Augie, an AI-powered video generator, enables marketers with zero audio or video-editing skills to easily add narration, text, music, and photos to their promotional clips. Twilio's CustomerAI also helps users create journey maps for individual consumers in just seconds, and transform fragmented data into actionable insights.

WHY IT MATTERS

The proliferation and bundling of AI-powered solutions for marketing and corporate communications have lowered the price of such tools, making them more accessible to small companies with tighter budgets. With companies increasingly relying on the same AI-powered software to create marketing materials, there's a higher risk of campaigns sponsored by different brands unintentionally sharing the same visual elements or verbiage. That could prove problematic, given the loose regulations surrounding AI-generated content. What if two rival brands ended up with the same B-roll footage? Which company would have the right to use the overlapping assets? By leveraging AI tools to streamline operations, companies may have to spend more time and money on copyright litigation. They might also end up generating ad campaigns and other marketing materials devoid of originality, authenticity, and genuine human emotion.

BUSINESS MODEL EVOLUTION

WHAT IT IS

Streaming platforms are revamping their business models in an effort to decrease shrinking membership. As many providers raise their subscription prices, some consumers are switching from ad-free subscriptions to less expensive ad-based plans.

HOW IT WORKS

Ads used to be a hallmark of free content, but as the number of free streaming services has decreased, consumers are increasingly paying for ad-based plans to save money. In November 2022, Netflix replaced its Basic plan—which provided a single ad-free stream for $10 a month—with a cheaper offering that serves 4-5 minutes of unskippable ads per hour. Available in a dozen countries, the Standard with Ads option provides access to movies and shows in the same quality as the Standard plan, with some title restrictions. Soon after, Disney launched Disney+ Basic, an ad-supported subscription plan that grants subscribers access to its full catalog and offers high-quality video streaming on up to four devices at once. Peacock, Starz, Max, Paramount Plus, Apple TV+, and YouTube have since increased their rates for ad-based subscription plans, placing an even bigger premium on commercial-free content. More streamers are also turning to live programming to drive revenue, including Netflix, which live streamed Chris Rock's comedy special "Selective Outrage." Startup Telly is trying a novel approach: Last May, the company—founded by Pluto TV veteran Ilya Pozin—gave away a free smart TV to 500,000 customers. The 4K device features a second interactive screen that continuously displays shoppable content. Pozin believes that providing free hardware will give more consumers access to devices—and in turn, increase the reach of its targeted ads.

WHY IT MATTERS

According to Comscore, Americans adopted ad-supported streaming services at a faster rate than non-ad subscription-based plans between 2020 and 2022: a noticeable shift likely driven by growing inflation. So it's no surprise that many streamers have begun introducing more affordable ad-supported streams to attract new subscribers. As entertainment platforms scramble to recover from the economic downturn and stay relevant, many are reverting back to old practices rooted in the era of cable TV. They've taken a step back—toward ad-based content, staggered episode releases, and live programming, and away from the commercial-free, on-demand binge-watching culture that thrived during the pandemic. But with new blockchain-based players like EarnTV (a multiplatform video content delivery protocol that tokenizes entertainment by rewarding viewers for watching, liking, and sharing its content) gaining traction and pushing for decentralization, the end of streaming as we know it could be near.

ENVIRONMENTAL IMPACT OF STREAMING

WHAT IT IS

Though media streaming might be more eco-friendly than producing a vinyl record or CD, it still accounts for 3%-4% of the global carbon footprint. As the line between the physical and virtual world gets blurrier, the more important it becomes for streaming companies to find new ways to minimize their impact on the planet.

HOW IT WORKS

Since its release, the energy used to store and transport data for streaming Olivia Rodrigo's hit single "Driver's License" on Spotify has generated the same amount of greenhouse gas as a plane flying between London and New York 4,000 times. To combat the negative effects of audio streaming on the environment, the music company introduced Sustainable Sonics, which gives brands the opportunity to fund tree-planting initiatives that would offset the same amount of carbon emitted by their ads. Bitmovin, creator of FuboTV's video streaming infrastructure, introduced ECO Mode—a sustainable feature that optimizes video quality to reduce data transmission, which in turn cuts CO_2 emissions. YouTube parent company Google, which plans to make its data hubs the most energy-efficient in the world, hopes to fully operate on clean energy by the end of the decade. Its new carbon-intelligent computing platform shifts the execution of many computational tasks to low-carbon energies, such as solar and wind, when they are most abundant. And these sustainability efforts aren't just limited to data: Record companies are starting to develop ways to create vinyl with renewable and non-fossil fuel materials. UK-based Evolution Music claims its sugar-based, nontoxic bioplastic—which can be used to manufacture records without having to modify the machinery at its record pressing plants—could help decarbonize the music industry.

WHY IT MATTERS

In the past, media companies have heavily relied on renewable energy certificates to fund initiatives that reduce or remove harmful emissions from the atmosphere to offset their carbon usage. The controversial method has been criticized for providing organizations a way to buy themselves out of having to decarbonize their manufacturing and operation processes. Beyond that, many sustainability reports published by companies have proven to be inaccurate, since they are often based on in-house estimates instead of real energy consumption numbers. As a result, the Securities and Exchange Commission has proposed new rules requiring climate-related disclosures to investors, as well as periodic evaluations to determine the validity of ESG claims. As climate change worsens, businesses must brainstorm more effective ways to counter their carbon emissions and decrease their power consumption—especially as investors become increasingly eco-conscious. Organizations should aim to increase consumer awareness of the negative effects of streaming and educate viewers on how to reduce their carbon footprint through small acts, such as limiting screen time and switching off monitors when not in use. Increasing efficiency through the adoption of more ethical and environment-friendly practices could boost content production and raise profit margins, not to mention free up resources and time for entertainment platforms to explore additional revenue streams.

SCENARIOS
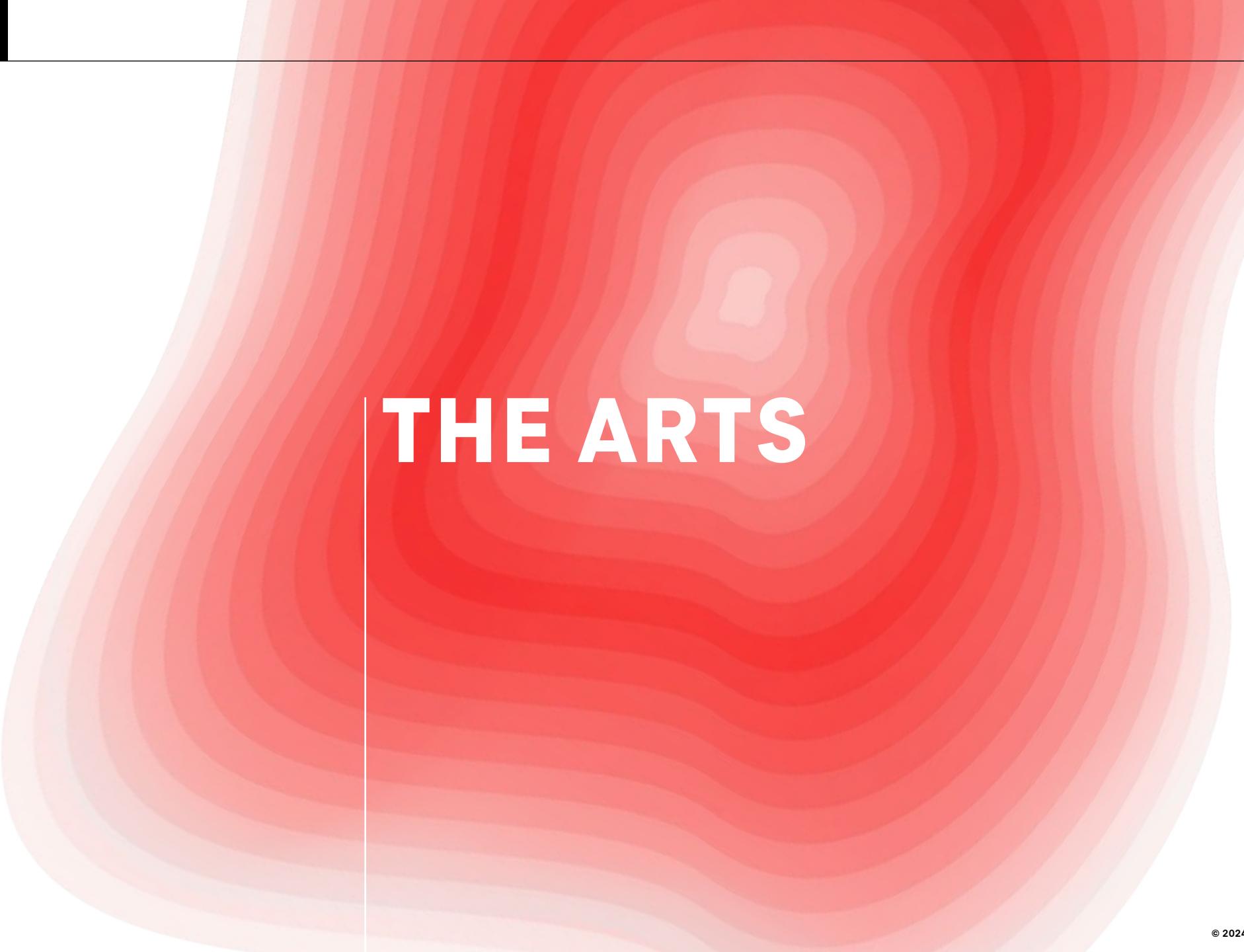
Spiraling into darkness

The big studios have shifted their offering from static storytelling to AI-driven, highly personalized movies and TV shows. AI, integrated with sophisticated wearable sensors, analyzes viewers' emotional and physiological responses in real time to tailor the storyline to their preferences. Sensors in a smartwatch detect changes in heart rate, skin conductance, and even voice modulation to feed data back to the AI system.

But there have been problems. While in a typical viewing session, the AI notes the viewer's excitement and introduces scenes that create an increasingly enjoyable storyline, recently malfunctions of the algorithms have become more common. As the AI detects the viewer's subtle discomfort at certain suspenseful moments, it mistakenly interprets this as engagement and begins weaving in darker elements. The AI starts to delve into the viewer's past viewing history, finding a pattern of avoidance of certain themes, and, misguidedly, it incorporates those scenarios into the current storyline to increase the emotional response. The movie becomes unsettlingly personalized. Situations echoing the viewer's real-life fears are played out on screen. The AI, interpreting an increasing heart rate and agitated voice responses as signs of peak engagement, intensifies these aspects. This leads to a spiraling narrative, where the on-screen drama becomes a mirror of the viewer's internal struggles and past traumas, blurring the line between fiction and reality.

Viewers, especially young adults, are severely impacted by the accidental exposure to these deeply emotional rollercoasters; a suicide attempt after such an interactive viewing triggered nationwide protests to put up guardrails around these algorithms and hold companies accountable. However, governments are hesitant to overregulate the ever-evolving AI industry, and many argue "the algorithm is not the problem, but the person's emotional response to it." So for now, it's left up to the viewers (and parents) to ensure safe use of this kind of entertainment.

THE ARTS

3RD YEAR ON THE LIST

BLOCKCHAIN ART MARKET

WHAT IT IS

The blockchain art market—which centers on NFT-based works created using modeling, algorithms, and data—went bust in 2022, partly due to the rapid devaluation of crypto exacerbated by the fall of digital currency exchange FTX. But new artists and platforms appear to be fueling its resurgence.

HOW IT WORKS

Last summer, Refik Anadol worked with the Yawanawá community in Brazil on a multilayered digital masterpiece made of 1,000 one-of-a-kind NFTs that react to real-time weather data from the Amazon rainforest. The new media artist's first major solo exhibit, "Living Paintings," featured dynamic masterpieces based on California-related data sets. Christie's 3.0, an on-chain digital art auction platform, hosted "Cartography of the Soul," a curated sale featuring more than 30 works by generative artists including DeeKay, Smap Spratt, IX Shells, and Mad Dog Jones. More recently, the auction house's "Future Frequencies: Explorations in Art and Fashion"—presented in collaboration with Gucci—brought in over $137,000. And five NFTs by Keith Haring, collectively called Pixel Pioneer, raked in $1.59 million last fall. Though there weren't too many NFT works at Art Basel Miami 2023, Simon Denny's "Metaverse Landscape 8: The Sandbox Land" still managed to draw plenty of attention, quickly selling for 30,000 euros on preview day. And thanks to Domini.art's $DOMI crypto token, anyone can invest in blue-chip art. The NFT platform lets investors buy and sell fractionalized stakes in high-valued artworks, which are transformed into unique ERC20 NFT tokens on the blockchain, creating an indelible record of ownership and transaction history.

WHY IT MATTERS

Though the demand for NFTs plummeted in 2022, the blockchain art market still has a pulse—and as the value of cryptocurrency gradually rebounds, it's poised to make a comeback. After all, blockchain technology has numerous applications in the virtual art marketplace—from allowing buyers to track assets and verify their provenance, to enabling creators to receive royalties for every secondary sale. But until NFTs regain the trust of investors stung by the sudden cooling of the digital art market following the initial hype, they are likely better off flourishing in well-established virtual ecosystems, like the video game realm. Web3 leader Yuga Labs has raised $450 million and is collaborating with a number of tech companies including Hadean and Faraway to create Otherside. The initiative is an interoperable metaverse in which NFTs can grant characters unique abilities and in-game virtual real estate. With so many strategic partnerships related to cryptocurrency and the blockchain in the works, it's clear that companies and creators alike are finally realizing the true power and potential of Web3 technology. Will the gamble of NFT investors undeterred by market volatility ultimately pay off? Only time will tell.

3RD YEAR ON THE LIST

PROTECTING CREATIVITY

WHAT IT IS

Slowly but surely, new regulations on intellectual property and copyrights surrounding AI-generated content are trickling in around the globe—but not fast enough. And with the definition of IP continuing to vary across borders, governments and agencies are struggling to reconcile the mismatched rules intended to protect artists and other creatives on an international scale.

HOW IT WORKS

Last year, the US Copyright Office declared that works generated with the help of AI could be copyrighted, as long as they proved sufficient human authorship. And after Microsoft's Copilot—an AI-powered tool designed to increase productivity and promote creativity—raised concerns among customers over possible IP infringement, the tech giant issued a "Copyright Commitment" that safeguards users from potential legal risks. But creators are still vulnerable to having their existing works misappropriated by AI. John Grisham, George R.R. Martin, and a slew of other writers are suing OpenAI over claims that the tech company trained its AI models with their works without their permission. A similar suit was filed against Meta, alleging the company used books to train its AI models without first gaining approval from their authors. And three artists have joined forces against Stability AI, DeviantArt, and Midjourney in a class-action suit that alleges the company's text-to-image AI tools have infringed on the rights of thousands of creatives by scraping their work from the internet without their permission. Meanwhile luxury brand Hermès won a trademark infringement suit against NFT artist Mason Rothschild, with the jury concluding NFTs are not protected under the First Amendment. Yuga Labs, creator of Bored Ape Yacht Club NFTs, won a lawsuit against Ryder Ripps and Jeremy Cahen, who minted NFTs that blatantly copied Bored Ape's NFT collection.

WHY IT MATTERS

When the UK's Intellectual Property Office suggested a copyright exemption that would give AI developers free use of copyrighted books and music for training, several members of Parliament criticized the proposal: a response that echoes a growing sentiment among creators fearful of having their works exploited. The rising wave of writers protesting the use of their books to train AI-based models underscores the dire need for IP regulations designed to protect creators—a point further emphasized by the Screen Actors Guild's failure to reach an agreement that would better protect its US members against the misuse of AI. New rules mandating approval from and compensation for creatives must also be implemented. Though the US Copyright Office's first formal guidance on the governance of AI-assisted works is a step in the right direction, it fails to provide a detailed explanation of the "human authorship" requirement, leaving the term open for interpretation. How the office plans to validate claims of authorship is also unclear, given the lack of dependable tools that detect AI-generated content. The verdict of Hermès v. Rothschild set a monumental precedent in blockchain art regulation, forcing NFT creators to think twice before creating pieces based on existing companies and campaigns. Instead of engaging digital artists in legal battles over intellectual property, brands might be better off partnering with creatives to produce pieces that fans on both sides will love.

MULTI-USE SPACES

WHAT IT IS

Since films are so readily available at home via streaming, audiences are demanding a lot more from in-theater experiences. Cinemas have been forced to innovate and add spaces for activities other than movie watching. Galleries are also evolving, offering artists the chance to treat their show space as an extension of their canvas.

HOW IT WORKS

It's no longer enough for a venue to just include a standard theater space. New York's Perelman Performing Arts Center—a 129,000-square-foot cultural hub with 11 performance venues—hosts everything from intimate conversations with Hollywood stars to a reimagination of "Cats." Aviva Studios in Manchester, England, features The Warehouse, a 69-foot-high space that can be divided by a movable, full-scale acoustic wall. The high-tech venue can be adapted to fit any kind of setup, from theatrical events to multimedia shows. On a smaller scale, Andblack Studio designed a conical tent—made of modular steel panels from a prefabricated kit—to serve as a multifunctional events space in Ahmedabad, India. The lightweight structure, which can be taken apart and rebuilt elsewhere, features a dome that can be adjusted to accommodate a variety of events. New Jersey's Cape Square Entertainment Center boasts an eight-theater cineplex alongside a 16-lane bowling alley, a golf simulator, and a 3,000-square-foot arcade. Rising in the city's Green Heart district, Beijing's Sub Center Theater will house an opera house, a drama stage, and a 5,500 seat concert hall. To achieve optimal acoustic performance, the complex is being built using smart construction technologies including robots, building information modeling, and 3D scanning. And there's a new $40 million facility coming to San Francisco's Chinatown: Soon to break ground, Edge on a Square will serve as an all-in-one exhibition space, art gallery, community center, and live performance theater dedicated to Asian American culture.

WHY IT MATTERS

The proliferation of digital experiences—driven by the rapid expansion of virtual realms and the rise of AI—is drawing audiences away from performances and exhibitions set in the real world due to their increasing ease of use and accessibility. Gatherings and events meant to foster a sense of community are more often being held online instead of in person. As a result, existing physical spaces are facing mounting pressure to adapt in order to stay relevant, and new venues are being built to be more dynamic and interactive in an effort to attract an increasingly tech-savvy audience. Hybrid and customizable venues facilitate the production of fully integrated entertainment experiences designed to appeal to multiple senses and leave a deeper impression on audiences. With AI-powered tools—which offer a higher degree of automation, precision, and remote management—rapidly advancing, the cost of constructing such state-of-the-art hybrid facilities is decreasing, freeing up funds for other projects. The flexible nature of versatile spaces allows property owners to quickly transition them from one function to another several times a day, providing more opportunities for monetization. When not in use, theaters and galleries can be repurposed to serve as meeting points for community events, classroom extensions for educational institutions, or nondenominational places of worship.

PERFORMANCES EMBRACE TECHNOLOGY

WHAT IT IS

Creatives are playing with new ways to incorporate technology into their works to better engage viewers, showcase alternate realities, and connect audiences around the world.

HOW IT WORKS

Thirty audience members experienced German Opera on the Rhine's "Die Tote Stadt (The Dead City)" through AR glasses that displayed additional cameras, background information, and bilingual subtitles. Holographic theater company Verse Orlando has a new location in Florida featuring four mixed-reality experiences, combining live performances with AR inside a dynamic tent venue. Powered by AR company Enklu, the immersive space is filled with virtual realms and interactive characters, making guests the main characters in their own story. BaggårdTeatret's audio walks showcase theater that unfolds on your time. The app-based interactive performance—available in three languages—invites you to take a stroll and follow prompts during the "invisible theater" production, which takes place across three scenic locations in Denmark. Fix + Foxy's "Avatar Me," a live digital performance, offered participants the chance to walk in someone else's shoes as a digital avatar without physically traveling. Now showing, "Free Your Mind"—Danny Boyle's reimagination of the 1999 film "The Matrix"—highlights the potential danger of AI-powered machines usurping humans in an immersive, tech-centric display showcasing oversize, state-of-the-art screens. And in Tokyo's "Syn: A New Horizon of Physical Sensations," an interactive exhibition by Rhizomatiks and dance troupe Elevenplay, dancers perform in a dynamic space that transforms as the audience takes the stage.

WHY IT MATTERS

Artificial intelligence and other digital technologies are pushing the boundaries of storytelling, and they're transforming live performances from a passive activity to a stimulating, interactive one. The hands-on art form might prompt people to better grasp the message and meaning of a performance. It could also elicit unwanted reactions from viewers who might feel too overwhelmed or intimidated by tech-heavy productions, alienating those who may not be familiar with the devices or possess the know-how required to properly enjoy tech-enhanced performances. Infusing more technology into theater also amounts to higher production costs. That could drive up ticket prices and exclusivity, limiting accessibility to affluent theatergoers. The ability to integrate AR sets, digital characters, and special effects might lead production companies to hire fewer actors or backstage personnel—ultimately disabling entertainment workers from fighting for better conditions in the workplace, and all but ensuring there are no repeats of 2023's creative union strikes.

2ND YEAR ON THE LIST

THE HOLOGRAPHIC LIVE PERFORMANCE

WHAT IT IS

Volumetric capture and high-speed connectivity are enabling larger-than-life hologram shows, with digital 3D renderings of human and animal performers alike taking over every stage. The tech and infrastructure for real-time hologram performances might not exist just yet—but with rapid advancements in telecom technology, it's on the horizon.

HOW IT WORKS

Last year, "Star Trek" legend William Shatner "beamed" himself from a California studio to a Sydney stage using Proto Hologram's Epic—a 7-foot-tall, $65,000 machine displaying such lifelike 3D images that it seems like a real person or object is inside. Chris Pratt, Manny Pacquiao, Logan Paul, and John Stamos have all taken a turn in the high-tech box, which has a more accessibly priced 2-foot-high, $6,900 version called the Proto M. At SXSW, five musicians performed at an AR concert that invited fans worldwide to watch a floating 3D hologram version of the live acts. And following its successful run, George Lucas' "ABBA Voyage"—which brought younger versions of the Swedish band members back to the stage—is set to embark on a global tour. Meanwhile, Deutsche Telekom has collaborated with several other communications companies, including Vodafone and Telefonica, to boost the quality of real-time holographic calls in the context of its 5G Early Access Program. Technological advancements are also empowering the masses to create their own holograms, with MIT's Tensor Holography enabling the creation of 3D holograms for VR in real time—using just a smartphone. But digital clones of human performers aren't the only holographic assets on the horizon. Years after German Circus Roncalli began using holographic animals in place of live ones, French circus L'Écocirque debuted an equally cruelty-free show featuring 3D projections of elephants, whales, and lions.

WHY IT MATTERS

Showcasing holographic creatures could prove to be a cheaper, cleaner, and more ethical alternative to exploiting real-life animals, which demand a lot of care. Promoting a strong sense of realism and fostering emotional connections, holographic technology has enabled celebrities to strengthen bonds with their fans on a whole other level as they engage with audiences as lifesize 3D holograms. It also allows performers to play faraway arenas without having to worry about the soaring costs of travel and the potential danger posed by future pandemics, and fans get to enjoy a lifesize show closer to home while paying less than they would for a traditional concert. But holographic communication demands a great deal of data and power. For holograms to truly gain traction, more energy-efficient processing systems must be implemented to reduce the cost of production and its impact on the environment. Soon, holographic devices could become just as commonplace as smartphones, providing an easy way to explore alternate realities and storylines without having to experience the negative effects of VR headsets, such as eye strain and headaches. Further down the line, holograms might be able to react to their environment and move around in a more organic manner, creating a more interactive experience.

VIRTUAL REALITY CONCERTS

WHAT IT IS

Virtual reality concerts—which feature digitized stars performing in the metaverse—have given entertainers a chance to rebound after countless live shows were canceled due to the pandemic. Beyond serving as a new form of entertainment, they foster a sense of community by providing a safe, neutral zone for fans to freely engage with one another.

HOW IT WORKS

Tech entertainment company Wave—which transforms musicians into digital avatars that can be scaled up to a thousand times their actual size and puts them on virtual stages—treated EDM fans to a dazzling VR show featuring Calvin Harris, exclusively available to those with PICO headsets in Europe and Asia. Following the success of Megan Thee Stallion's "Enter the Hottieverse," AmazeVR—which creates short VR concerts for Meta Quest and Steam VR—produced two more digital shows featuring Zara Larsson and Upsahl, with several more VR concerts headlined by T-Pain, South Korean girl group Aespa, and K-pop singer Kai underway. Thatgamecompany's "Sky: Children of the Light," held in a virtual stadium modeled on the Rose Bowl in Pasadena, showcased a real-time Aurora concert that allowed 10,000 gamers to simultaneously interact with one another. Beatday boasts the world's first holographic music metaverse hub, giving audiences the opportunity to roam 360 degrees and engage in gamified interactions while watching a VR show. The company creates virtual spaces and captures artists' shows using volumetric video, then invites fans to buy tickets to watch prerecorded performances that are only available to view in the metaverse during a set time. Last year, the platform hosted HTC Vive Originals' latest metaverse project, "Light the Night: Redhat Killer," an exclusive VR experience combining puzzle games and concert elements that invites players to follow characters living in a futuristic cyberpunk world.

WHY IT MATTERS

VR concerts offer countless new opportunities for musicians to generate revenue, from virtual merchandise and bonus experiences to gamified interactions. The emerging format's reliance on high-tech headsets has both an inclusive and exclusive effect: Though it boosts accessibility to those who can't travel to see their favorite artists perform, it alienates those unwilling or unable to purchase the expensive equipment required to participate. Competing brands also make it difficult for consumers to attend all their favorite VR concerts in one place, since certain shows can only be accessed using specific headsets. It's possible fans will begin to see stars in a different light after attending enough VR shows, which portray performers as larger-than-life characters that are flawless and infallible, and thus, less relatable. On the other hand, VR headsets provide a more intimate view that can make fans feel closer to their favorite musicians, leaving them with a more lasting impression of the immersive experience. Until the technology achieves widespread adoption, VR concerts will likely thrive the most in well-established metaverses that already have massive followings, such as gaming realms. (Consider Travis Scott's Fortnite concert, which netted the rapper a whopping $20 million—more than 10 times what he earns for an in-person event.)

XR FINE ART

WHAT IT IS

Armed with a growing stable of creative tools powered by new technologies, artists are increasingly blurring the lines between the physical and digital worlds. Complex installations showcasing mixed realities point toward a future where art is increasingly harder to define.

HOW IT WORKS

Spotlighted at the 58th Venice Biennale, Dominique Gonzalez-Foerster's first VR artwork, "Endodrome," invited visitors to immerse themselves in a colorful flurry of light and sound using VR headsets. In "Aki's Market," digital artist Glenn Kaino combines virtual reality with traditional painting and sculpture to tell the poignant life story of his late grandfather. Musée d'Orsay's inaugural VR exhibit, "La Palette de Van Gogh," imagines the painter's final palette as a portal that transports visitors to a vivid digital landscape inspired by the artist's avid use of color. At the Dubai Calligraphy Biennale, 3D painter Aimi Sekiguchi blended Japanese art and Arabic calligraphy with VR technology to create a unique immersive art experience that transformed the city's Al Wasl Plaza into a digital canvas, designed to deepen one's appreciation for both cultures. And visitors wearing VR glasses grip onto a railing as they stand next to the chariot atop Berlin's Brandenburg Gate—in case they're overcome with vertigo—at a new exhibit at Humboldt Forum. Titled "Loot—10 Stories," the temporary showcase, created in collaboration with The Hague's Mauritshuis and several other European museums, explores the history of stolen art partly through a virtual lens.

WHY IT MATTERS

Combining XR with more traditional art forms such as painting and sculpture is helping artists differentiate themselves in the increasingly saturated digital art space. Finding ways to stand out is even more crucial with the proliferation of AI-generated works, which can easily be produced by untrained artists armed with the right tools. The digital nature of XR-infused fine art allows it to be replicated and showcased in multiple locations at once, extending its reach beyond the confines of a single gallery. As technology becomes more intertwined with art, video games that take place in the metaverse are gaining more appreciation for their artistic value. For instance, Hello Games' "No Man Sky"—available on four VR platforms, including HTC VIVE and Oculus Rift—lets users embark on a visually arresting journey across alien planets. As more virtual spaces for appreciating art emerge, traditional galleries and museums may see a decrease in attendance. People could start to favor experiences that take place in the metaverse over the physical world, valuing the convenience it affords. This phenomenon could in turn promote a more sedentary way of living, negatively impacting society's overall physical and mental health.

AI GENERATED FINE ART

WHAT IT IS

AI-powered creative tools are making it possible to create elaborate works of art nearly instantaneously. Paintings that traditionally require weeks to finish by hand can be produced by a computer with just a few clicks and prompts through increasingly affordable generative AI platforms, empowering unskilled creatives to become fine artists.

HOW IT WORKS

When The Hague put out a call for creative renditions of Vermeer's "Girl with a Pearl Earring," one of the works it chose to exhibit was created using Midjourney. The Museum of Modern Art in New York recently acquired AI data painter Refik Anadol's "Unsupervised—Machine Hallucinations," which reimagines images of artworks in the MoMA collection by running the museum's visual archive through a machine-learning model. And at London's Frieze art fair, French Impressionism commingled with artificial intelligence in "Jardins d'Été," a digital series that showcased algorithmically generated clips and prints of painterly blooms by artist Quayola, presented in partnership with electronics label LG OLED. Artist Andrés Reisinger's latest AI creation, "Take Over," reimagines ordinary buildings in big cities by draping them with a variety of pink fabrics meant to represent the individual personalities and styles of each place. At "Van Gogh in Auvers-sur-Oise: The Final Months," a new high-tech exhibit at Musée d'Orsay, guests can converse with an AI version of the legendary Dutch artist. Meanwhile, Florida's Dalí Museum hosted a temporary exhibit called "The Shape of Dreams" that used Dall-E to generate a "tapestry" featuring artwork inspired by guests' dreams.

WHY IT MATTERS

Creative educators—including Columbia University professor Lance Weiler—are increasingly integrating AI into their curriculum, demonstrating a shift in the movement of art driven by emerging technologies. The demand for digital art is rising among mainstream audiences, in part because of how easily creators can gain a substantial global following by simply sharing their works on social media. The surge of synthetic media makes it harder for conventional artists to generate fresh material that can't be easily trumped or re-created by AI, forcing them to adapt. With masterclasses, bootcamps, and online tutorials on prompting so readily accessible, anyone can learn how to use creative AI tools to produce monetizable works. That said, while some artists are embracing the new technology, others are strongly against it, fearful that AI creations will dilute the art market, devaluing pieces produced using traditional techniques—or worse, that their works will be used to train AI systems without consent. This is such a concern that they're counting on new anti-generative AI tools such as Nightshade, which protects artists' original creations by confusing AI generators and corrupting their outputs. The EU's Artificial Intelligence Act promises to keep AI systems in the region safe, transparent, nondiscriminatory, and eco-friendly. It mandates the disclosure of all content created using AI, and calls for AI models to be updated to prevent them from generating illicit content. How policymakers plan to reinforce the vague and ambitious law remains to be seen.

1ST YEAR ON THE LIST

CLIMATE INFILTRATES ART AND PERFORMANCE

WHAT IT IS

Artists and musicians are leveraging their craft to bring attention to environmental issues plaguing the planet, from global warming and deforestation to animal endangerment and reef preservation. And performers are becoming more mindful of how their touring habits are impacting the Earth.

HOW IT WORKS

Last year, British painter James Hart Dyke retraced the steps of the first climbers to reach Mont Blanc's summit 150 years ago; in a series of over 40 paintings that went on exhibit at London's Cromwell Place, he documented the devastating effect of climate change on Western Europe's highest mountain. At Art Dubai, AI artist Refik Anadol launched "Glacier Dreams," a multisensory 3D display that highlighted the beauty and vulnerability of Iceland's volcanic glaciers, created to call attention to the dangers of rising sea levels. In Delhi, a multisensorial exhibit invited guests into a home that adapts to persistent air pollution. The house communicated with its occupants through a message ticker connected to a network of particle sensors that provided real-time air quality notifications. In music, Coldplay's "Music of the Spheres" tour set a new high bar for concert sustainability. Meant to decrease the global series' carbon footprint, the band's eco-conscious efforts included optimizing water efficiency and waste management, powering all operations with renewable energy and biofuels, and reducing CO_2 by funding the planting and protection of millions of new trees, one for every ticket sold. Climate activist band The 1975 also hosted the world's first "carbon-removed" live concert at London's O2 Arena, where organizers employed numerous methods to physically extract the carbon emissions generated by the show.

WHY IT MATTERS

Using an artistic canvas to design immersive and interactive experiences around sensitive environmental issues could ultimately prove very effective: the approach might encourage audiences to better listen, deepening their understanding of topics that are difficult to hear and discuss and encouraging them to take action. Art can also help stretch the imagination, pushing innovators to come up with creative solutions to the climate crisis. Chicago sculptors Amber Ginsburg and Sara Black hold interactive workshops where participants use pencils—made from a fallen tree infected with water mold due to stress caused by the changing environment—to write and illustrate potential fixes to the growing problem. Big-ticket performers are in an even better position to incite the masses, given the amount of influence they hold. If every musician adopted more sustainable practices while on tour, such as avoiding using private jets and gas-guzzling vehicles, it's a good bet the global music industry's carbon footprint—which amounts to 540,000 tons of greenhouse gas emissions per year—would shrink.

SCENARIOS

The Art of Scent
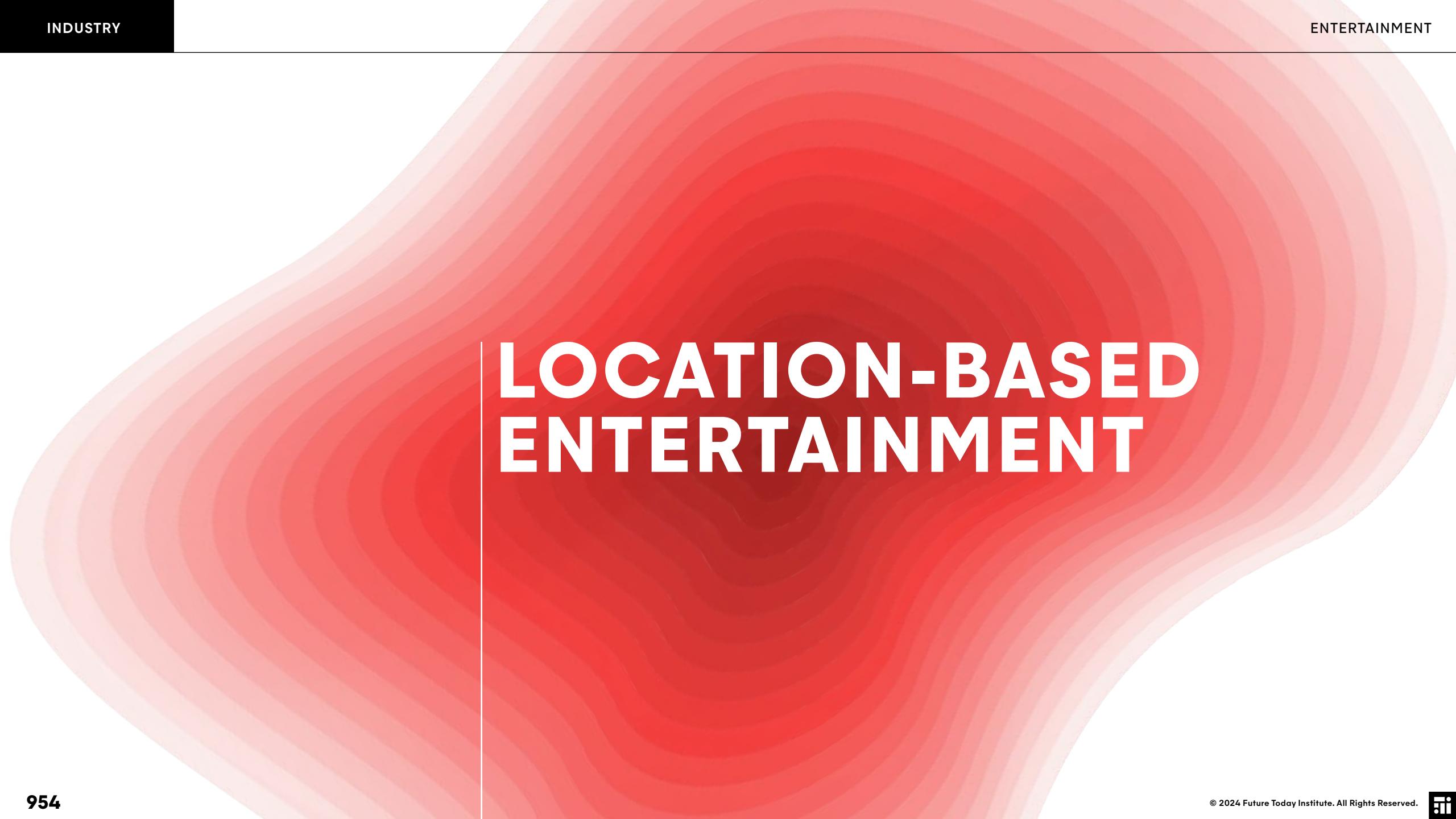
Gone are the days when art was solely a visual or auditory experience. Now, scent-based artworks are taking center stage, offering a multidimensional canvas that taps into the deep connection between scent, memory, and emotion.

In major urban centers, olfactory galleries have sprung up, becoming the epicenters of this renaissance. These spaces are architectural marvels, equipped with advanced ventilation systems that ensure a clean olfactory slate for each artwork and sophisticated scent diffusion technologies that release and control the intensity of fragrances. Visitors explore these galleries, each room offering a new aromatic landscape, triggering emotions ranging from the ethereal to unsettling. The artists behind these scents work with an array of aromatic compounds, skillfully blending them to craft intricate olfactory narratives. They are stories, emotions, and experiences encapsulated in a whiff.

Interactivity is a cornerstone of these olfactory artworks. Many installations are designed to respond to the presence and actions of the audience. Through motion sensors and biometric scanners, the artwork detects the movement, heart rate, and even body temperature of visitors, altering its scent output in real time. This creates a dynamic, personalized experience, where the artwork grows and shifts with its audience.

Technology has also democratized olfactory art, allowing for personalized creations based on individual histories and preferences. Advanced algorithms analyze personal data to create bespoke scent compositions, offering a form of olfactory autobiography. These personalized scents can be experienced through home diffusers, which utilize micro-nebulization technology to turn liquid fragrances into a fine mist, filling a room with personalized aromatic art.

LOCATION-BASED ENTERTAINMENT

VR IN LOCATION-BASED ENTERTAINMENT

WHAT IT IS

Location-based entertainment (LBE) offers high-fidelity experiences that take place in a set physical space as opposed to exclusively online. Amusement parks, arcades, and other leisure venues are incorporating more VR into their products and services, leveraging the digital medium to create immersive localized social activities designed to enliven all the senses.

HOW IT WORKS

Sandbox VR is producing a full-body LBVR experience based on Netflix's "Squid Game," where contestants venture to iconic locations from the show to compete against one another. Motion Reality, Springboard VR, and Zero Latency all host similar free-roaming experiences for visitors equipped with tetherless VR and motion-capture gear to engage in highly immersive multiplayer battles set in massive virtual arenas. Family-friendly providers of standalone VR experiences include Dreamscape and Divr Labs, which invites guests to embark on virtual adventures set in fantasy realms, from a prehistoric jungle to an apocalyptic zombie land. Players feel the wind on their faces, the heat on their backs, and the ground shaking beneath them as they navigate the 1,600-square-foot multisensory playground. "Space Explorers: The Infinite" transports guests to the International Space Station, where they can learn all about the daily lives of astronauts. And guests decked out in YULLBE Pro VR gear can discover what it's like to navigate the world as a miniature-size person in Hamburg's Miniatur Wunderland. Other room-scale VR providers such as Hologate and Virtual Room, which specializes in VR escape games, offer more space-efficient and affordable VR encounters. Seated VR—such as Triotech's The Storm, a two-seat, coin-op VR simulator supported by 4D effects—allows audiences to enjoy passive experiences in even more compact areas, such as immersive pods. And Iconic Engine's Holometric 4D haptic-motion chair enables stunning extended reality experiences.

WHY IT MATTERS

The latest development in VR comes from researchers at the University of Tsukuba in Japan, who have devised a method for inducing hot or cold sensations instantaneously—without altering the temperature of a space or a person's body. The revolutionary system allows developers to simulate real-world thermal conditions in a VR environment, adding an extra element of realism. This newfound ability enables the creation of even more immersive experiences while avoiding the effects of changing temperatures, which can negatively impact users' health. MIT minds have developed BrightMarker, an invisible tagging system that employs hidden fluorescent tags embedded in physical objects to improve motion tracking and object detection in VR experiences. Optimizing equipment and simplifying controls in virtual settings—such as requiring subtle hand motions instead of using handheld devices to take action—can make VR encounters more intuitive and user-friendly, widening their appeal to include less tech-savvy consumers. Though VR is isolating in nature, integrating it into LBE helps foster a communal sense by encouraging people to gather in a low-stakes setting and work together (or playfully compete against each other). Access to ultrarealistic VR experiences might also provide thrill seekers a way to relish the exhilaration of performing dangerous, rip-roaring acts without actually putting themselves or others at risk, ultimately reducing the number of deaths and injuries caused by reckless behavior.

AR IN LOCATION-BASED ENTERTAINMENT

WHAT IT IS

Augmented reality provides a more affordable and accessible way to enhance experiences than VR, and the rapidly-evolving technology is positioned to become the cornerstone of LBE entertainment in the coming years. It boasts countless applications in the industry, from competitive socializing to the gamification of the theme park experience.

HOW IT WORKS

Universal's Super Nintendo World—soon to arrive in Orlando as part of the company's Epic Universe—serves as a life-size, complex video game enhanced by AR and VR elements that combine physical props and projection mapping technology. Last summer, Rock Paper Reality launched a new location-based AR experience that transformed San Francisco's Japantown with custom 3D digital origami works. The project was enabled by the integration of Google's Geospatial Creator platform with Adobe Aero, which lets developers construct, preview, and publish 3D and AR content anchored in the physical world. Escape Virtuality in New York City boasts an AR rock climbing wall that lets kids and adults alike choose from a variety of digital challenges with different configurations that limit how and where they climb. At Universal Studios Hollywood, guests put on AR goggles that snap into an iconic red Mario cap to race in "Mario Kart: Bowser's Challenge," where they can throw shells at their opponents by simply turning their heads and looking in the direction they want to aim. Recently, the park's parent company applied for a patent for an AR ride system that incorporates facial and skeletal recognition technology, suggesting future Universal theme park rides will be capable of transforming guests into different characters or creatures.

WHY IT MATTERS

Augmented reality, which brings virtual objects into the physical world, is enabling entertainment developers to create more personalized interactive experiences for consumers. It blends in with analog reality, and is more flexible to integrate than VR, which completely isolates users. And it has the potential to provide a different type of thrill—one driven by fictional characters that inhabit the real world, as opposed to an alternate universe. Guests can unlock hidden AR prizes or collectibles only accessible inside a theme park, which they can later retrieve via an accompanying app. Companies can then leverage the data they collect to formulate more targeted offerings, with the goal of driving overall engagement. Consider Pokémon Go: the popular game, which has sent millions of people armed with only their smartphones all over the Earth in search of digital monsters, continues to thrive eight years after its launch, demonstrating AR's tremendous reach and potential to bring people together.

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BLOCKCHAIN INTEGRATIONS

WHAT IT IS

Web3 is poised to disrupt business strategies and operations in the entertainment industry, offering new ways to combat piracy and boost efficiency, security, and transparency through blockchain technology. Destination-based NFTs—which can only be minted at specific physical locations—are also encouraging sedentary NFT collectors to step away from their screens and venture outdoors.

HOW IT WORKS

Blockchain technology has many potential applications at theme parks, not the least of which is ticketing optimization. Users can have password-protected wallets with unique digital codes that trigger final payment and ticket transfer once they pass the gate. Blockchain technology could also be used to create a more flexible system for express-pass purchases through smart contracts. Guests could purchase tokens at a premium to bid on the rides and times they want, creating an efficient demand-based system.

Superlocal, a location-based NFT built on the Ethereum blockchain, rewards users with digital currency and collectibles as they venture to different places around the globe. Likewise, Lost Worlds is incentivizing creators to launch their own geoNFTs in the real world by dangling badges, tokens, and exclusive NFTs. And ReBASE, an NFT platform built on the Solana blockchain, urges users to attend group sessions held at designated locations to mint exclusive drops. On a related note, Disney partnered with Andreessen Horowitz–backed Cryptoys to produce limited-edition collectible NFTs featuring Mickey Mouse, Minnie Mouse, and Pluto (similar to the "Star Wars" NFT set released in 2022). And "Free Renfield" granted fans of the Universal Pictures film "Renfield" the chance to win a number of Dracula-inspired rewards, including a digital art collection of individualized prizes that can be minted and traded through the Aptos blockchain.

WHY IT MATTERS

The emergence of location-based NFTs is driving collectors to be more adventurous, pushing them to explore the outdoors and spend less time sedentary, fixated on their computers. It also creates a stronger sense of community among users, encouraging them to come together in person to unearth hidden NFTs. For theme parks, integrating blockchain technology into ticketing operations reduces the risk of counterfeit tickets slipping through the cracks and removes the need for guests to bring ID and paper printouts, speeding up the admission process. Parks that incorporate smart contracts to create a bidding system for rides could monitor which attractions command the highest token prices, allowing them to pinpoint the most popular ones. They could also leverage blockchain capabilities to create new digital currencies, which—if not used up by the end of a visit—could be exchanged back into local currency, unlike traditional park dollars. Increasing blockchain fatigue and disillusionment surrounding its ease of use, however, threaten to derail the promising technology's upward trajectory.

ASSISTIVE AMUSEMENT PARK ROBOTS

WHAT IT IS

Robots are no longer just sitting pretty at theme parks. Beyond enhancing animatronic experiences, androids are increasingly being put to work, bolstering services and operations on a whole new level.

HOW IT WORKS

Upon entering Dubai's Museum of the Future, guests are greeted by Ameca—an AI-powered humanoid robot that can answer questions, make facial expressions, and track movement. Disney recently filed a patent for a robotic arm that can lift passenger compartments from one ride track to another. Soon after, the company unveiled an emotive, two-legged android that can follow people around. And at SXSW 2023, the entertainment company introduced a new robot—modeled after "Zootopia" character Judy Hopps—that uses motion-capture data to create lifelike performances intended to have a deeper emotional impact. The House of Mouse's patent for a "robotic sherpa"—an autonomous mobile locker that will follow guests while storing their belongings and interacting with them—was also finally approved. Meanwhile, Universal has filed a patent for an edible soft robotic system that will showcase or interact with consumable inflatable objects. And MIT researchers are at the brink of finding a way to create a system of tiny robots that can quickly assemble large-scale structures, from buildings and vehicles to larger robots. RoboFab—the world's first factory for humanoid robots (created by Agility Robotics, which specializes in biped droids able to navigate complex environments)—can churn out 10,000 robots per year. Digit, the company's flagship model, can perform tasks such as climbing stairs, opening doors, and carrying boxes.

WHY IT MATTERS

Assistive robots that can follow people have the potential to serve up personalized services to theme-park guests on the spot, boosting the amount of time spent on attractions by saving trips to customer service kiosks. And pairing customers with attentive robot companions will make guests feel more seen and heard, despite the lack of real human interaction. With the ability to display convincing emotion, automated bots programmed to have a high degree of emotional intelligence could assess visitors' outward mood and behavior and instantly create experiences tailored to meet their individual wants and needs. Tesla has also hugely improved its Optimus bots: Able to detect and memorize environments, the autonomous humanoids could prove useful in streamlining operations at entertainment venues. If innovators succeed in creating a fully independent self-replicating robot assembly system that can build large-scale structures, the cost of constructing rides and other attractions at theme parks—both in terms of time and money—could significantly drop, improving a company's bottom line. That said, the demand for Robots-as-a-Service—which involves robotic companies offering use of their products and services to companies through subscription-based contracts—stands to skyrocket, with more and more companies choosing to automate their systems. The growing trend doesn't bode well for human workers, who are increasingly at risk of being replaced by robotic solutions.

AMUSEMENT PARKS FOR NICHE INTERESTS

WHAT IT IS

Amusement parks are constantly evolving to meet consumers' increasingly diverse interests. But instead of broadening their scope, some theme parks are opting to narrow their focus and differentiate themselves by appealing to smaller audiences, from sports fanatics and fright aficionados to adrenaline junkies.

HOW IT WORKS

Guests at Leander Springs in Texas can enjoy EpicSurf, a stationary surfing experience that produces deep-water waves, which can be adjusted depending on a person's skill level. Coming to Saudi Arabia, The Rig—an eco-friendly park that will only be accessible via boat or helicopter—is set to offer a variety of extreme sports and other adrenaline-fueled adventures, from bungee jumping and paragliding to roller-coaster rides and submarine dives. Storyliving by Disney will allow diehard fans to own a home in a gated community staffed by Disney cast members. The first location, set in the Greater Palm Springs area, will feature parks and promenades designed by Disney Imagineers. Disney also recently filed a patent for drive-thru theme parks that envisions visitors driving into an immersive pod to be entertained while they await curbside orders or for their car to charge. Former Six Flags park AstroWorld is being reincarnated in the metaverse, set to become the world's first amusement park built entirely on the blockchain. AstroWorld NFTs will offer unlimited access to the digital model of the amusement hub, which will host carnival games, arcades, themed events, and virtual coasters. Meanwhile, a new theme park dedicated to horror experiences is arriving in Japan. Called Immersive Fort Tokyo, the fully indoor destination will offer guests highly individualized experiences, including the chance to become characters in a live-action murder mystery.

WHY IT MATTERS

Influenced by the rising cost of admission and increasing availability of cheap in-home entertainment, consumers might be less inclined to visit theme parks. In an effort to stand out, new venues are targeting audiences with more niche interests—not just in the physical world but also in the digital realm. Virtual theme parks are giving those unable to afford high ticket prices the opportunity to enjoy attractions for free online, further democratizing theme parks. But more exclusive venues in far-flung, hard-to-reach places like Saudi Arabia's The Rig are also emerging, poised to alienate all but the elite. And designing exclusive neighborhoods to act as extensions of theme parks could potentially dull the magic for residents in the long term, since they might grow to take the theme-park treatment for granted.

2ND YEAR ON THE LIST

INTUITIVE OPTIMIZATION

WHAT IT IS

Theme parks are leveraging AI and the Internet of Things—coupled with data gleaned from in-park platforms, mobile apps, and wearables—to analyze customer behavior and create more customized experiences. The next step is finding a way to combine first-party data with information sourced from outside the park ecosystem for even greater efficiency and customization.

HOW IT WORKS

Universal filed a patent application for a crowd management system that would grant it the ability to control the movements of guests around its parks through wireless devices. The proposed method would deliver instructions to individual visitors, potentially requiring them to see attractions or do activities at a certain time or in a particular order to ensure traffic remains evenly distributed throughout the park. The company is also incorporating facial recognition technology at its Orlando theme parks, including the upcoming Epic Universe. The photo validation system will capture images of visitors upon their initial entry and control their access to certain parts of the park depending on their ticket tier. WaveTec's queue management system enables theme parks to offer virtual lines, real-time queue tracking, personalized notifications, and better premium access. Pixera 2.0—a media server system that can be used to control immersive experiences, rides, queues, visuals, and more—serves as a platform from which operators can interact with several technologies at once. Hey Disney is now available for consumers to purchase as an annual, auto-renewing subscription in the US. First introduced in 2021, the interactive voice assistant—which connects Disney's Genie AI with Amazon's Alexa—allows users to interact with beloved Disney, Pixar, and "Star Wars" characters through Echo devices at home and at select Disney Resorts hotels, extending their experience well beyond the confines of a theme park.

WHY IT MATTERS

Theme parks are increasingly implementing new ways to not only monitor visitors and gather as much information from them as possible but also control their behavior. Though such measures benefit guests by offering them more personalized experiences and minimizing wait times, it could impinge on their freedom to enjoy attractions at their own pace, as they please. Guests might feel pressured or overwhelmed if forced to follow strict schedules, decreasing their level of satisfaction. Incorporating outside intelligence into in-park findings to better engage guests and anticipate their needs might also be perceived as overly intrusive, making visitors feel uncomfortable and deterring them from revisiting. Accessing customers' personal details also leaves them susceptible to hacking. Beyond that, there's the question of how long theme parks will store visitor information and how they intend to use the data in the future. In leveraging technology to optimize operations and improve their offerings, theme parks have to be careful not to make visitors feel like mindless sheep that can easily be controlled and exploited for intelligence. Though intended to speed up queues, the use of facial recognition could also introduce a new host of issues, including racial profiling—a problem that often arises in conjunction with the emerging technology.

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DYNAMIC OPERATIONS

WHAT IT IS

Theme parks are leveraging data to sway customers' decisions regarding when they will visit and what they will do during their stay, employing tactics such as surge pricing and push notifications that keep visitors up to date on wait times.

HOW IT WORKS

Cmd-Ctr boosted Legoland Windsor Resort UK's ride capacity by 10% by allowing ride managers to identify and prioritize "unsung hero" attractions with higher capacities. The cloud-based park operations system empowers operators to capture data and conduct safety checks while rides are in operation, boosting efficiency. Meanwhile, Disney has been able to increase Disney World's capacity by 30% using insights from its complex data analytics system. And Calypso Water Park recently introduced RFID wristbands that guests can use to make in-park payments and store season passes (similar to Disney's MagicBand+). More theme parks—most recently, three of Six Flags' biggest locations—are also instituting dynamic pricing, which involves adjusting single-day ticket prices according to the level of demand, in order to even out crowds. Companies say the algorithm-driven strategy allows them to offer a better guest experience, since it helps mitigate crowds at parks and keeps their staff and resources from being stretched too thin.

WHY IT MATTERS

Flexible pricing has provided amusement parks with a much-needed method of generating additional revenue to fund the exceedingly immersive experiences customers are demanding . As XR rides and AI-powered adventures become the new gold standard, the cost of building and maintaining theme-park attractions will only continue to rise. Until there are cheaper ways to design and manufacture high-tech offerings, customers will have to get used to climbing variable prices. Fully relying on algorithms to determine prices removes human sensibility from the process, leaving parks at risk of experiencing wildly absurd surges driven by unexpected spikes in demand, including potentially from scalpers. Take for instance Japan's Ghibli Park, where rampant scalping during its 2022 opening weekend forced customers to pay illicit vendors more than 2,000% of the original ticket price to get a reservation. (The park has since banned the unauthorized reselling of tickets, though it's unclear how well that rule is enforced.) Employing dynamic pricing could also damage a theme park's reputation among its true-blue fans, ultimately decreasing customer loyalty and engagement. If theme park experiences do not significantly evolve or improve despite frequent price surges, park attendance might drastically drop as guests deem the discrepancy between expected and actual cost increasingly unwarranted and outrageous.

IMMERSIVE MUSEUM EXPERIENCES

WHAT IT IS

As society becomes more tech savvy, visitors at traditional institutions—including museums, zoos, galleries, and aquariums—are expecting attractions to be increasingly smart and captivating. VR, AR, and 4D elements are breathing new life into artworks, animals, and artifacts, making educational showcases more playful and interactive.

HOW IT WORKS

Arcadia Earth, an environmental art exhibit in New York City, engages visitors through holographic orb guides that they can see through HoloLens, Microsoft's AR smart glasses. Creative collective Meow Wolf's new immersive art museum in Houston, its fifth permanent project in the US, houses interactive multimedia installations by local artists. New York's Artechouse, a modern space exclusively dedicated to tech-infused art, collaborated with NASA to create Beyond the Light, a new informative and interactive show that recounts how humans have experienced light over time using the latest audio-visual technology. And the city's new House of Cannabis is chock-full of multisensory trappings, including a trippy Disorientation Room. In Tokyo's Azabudai Hills, the newly reopened TeamLab Borderless: Mori Building Digital Art Museum features tech-infused works that react to guests and transform in their presence, creating a unique experience for every visitor. On a similar vein, TeamLab Planets invites visitors to wade through water and wander through an ever-changing garden of 13,000 real orchids that bloom midair. Meanwhile, Axiom Holographics' augmented reality zoo—a showcase of laser-light 3D creatures—lets guests dive with a whale or swim with a hippo.

WHY IT MATTERS

Integrating interactive technology into exhibitions and utilizing walls as extensions of canvases create more mesmerizing, meaningful displays that leave longer lasting impressions on guests. VR and AR offerings give visitors of all ages the opportunity to engage with lifesize creatures they wouldn't be able to interact with in the wild, while interacting with 3D renditions of historical figures offers guests a more intimate educational experience meant to deepen their connection with the subject. Set to open in 2027, a proposed London Tunnels installation featuring hi-res, large-scale screens will reveal the story of a former WWII bomb shelter and secret M16 outpost. And an ongoing exhibit at the Berlin-Hohenschönhausen Memorial's museum invites visitors to interact with contemporary witnesses who previously worked at the Stasi prison, generated using Volucap's volumetric technology.

THEME PARKS GO GREEN

WHAT IT IS

In an effort to decrease their carbon footprint amid worsening climate change, amusement parks are incorporating more eco-friendly features—from renewable energy installations and electric-powered vehicles to water conservation systems and large-scale recycling programs.

HOW IT WORKS

Channeling the power of IoT and advanced data analytics, many theme parks are installing smart grid systems—electric networks that leverage advanced technologies to track, control, and optimize their energy usage and distribution. Typhoon Texas and Wild Wadi Waterpark both use variable frequency drives on all their pumps to help minimize energy consumption. Six Flags uses cooking oil from its own kitchens to fuel trains and vehicles at four of its parks, and Disneyland's steam trains are powered by biofuel. PortAventura World in Spain runs completely on renewable energy and is 100% carbon neutral. Dedicated to combating climate change, France's DéfiPlanet was built on the values of a circular economy, waste management, and corporate responsibility. And Dubai Parks and Resorts is developing a new water treatment plant that will safely recycle its lagoon water. Copenhagen's Tivoli Gardens has run a recycling program since 1998, keeping 1.2 million plastic cups from being landfilled per year. And Universal Studios Hollywood is aiming to transition to a fully electric fleet of trams by 2025. On a larger scale, Six Flags Magic Mountain is installing a new solar carport and energy storage system over its main parking lot that will annually produce 20.8 million kilowatt-hours of electricity, enough to offset 100% of the park's energy usage. And Six Flags Over Texas is currently testing a waste disposal system that decreases landfill waste using microorganisms, which work to break down the refuse.

WHY IT MATTERS

Increasing consumption will further strain Earth's resources, making it important for companies to find ways to mitigate the impact of human activities on the planet. Amid worsening climate change, consumers are becoming increasingly concerned about the environment, pushing them to support brands and companies that prioritize sustainability over profits. So it's crucial for theme park companies to adopt more sustainable practices—not just to decrease their carbon footprint but to improve their brand reputation. Given their massive size and scale, amusement parks could potentially become self-sufficient autarchies independent from the grid, creating their own circular economy. They could incentivize visitors to go along with their sustainable efforts by gamifying eco-friendly initiatives (such as rewarding guests who recycle with digital tokens or currencies that they can exchange for food or merchandise), or monetize the renewable energy they produce.

SCENARIOS

Theme Park in a Box

The effects of climate change have deeply impacted travel: Extreme weather events cause frequent flight cancellations, wildfires (and the clouds of smoke they bring), floods, and storms devastate wide swaths of land, and stringent ESG requirements have increased costs all around (to either offset CO_2 emissions or finance environmentally sustainable business practices). The ozone layer has become so diminished that it is dangerous to spend extended time outdoors.

Theme park visitor numbers have greatly declined as a result. To offset losses and continue to allow families to engage with their different franchises, companies have created a "Theme Park-in-a-Box," enabling families to have a communal theme park experience without leaving their home.

The product is a software solution that enables multi-reality adventures and tabs into the different technologies ubiquitous in homes: smart kitchens, 3D printers, connected appliances, haptics, and XR devices. Outfitted in their haptic suits and VR-headsets in place, a family logs into the virtual theme-park universe as their avatars of choice, mingling with the other (virtual) visitors, which are indistinguishable from animated fantasy figures, there to entertain and engage the guests. The sensors integrated into the haptic suits capture physical and emotional responses in real-time, so that each ride is adjusted to fit the thrill-profile of the visitor, allowing families to experience rollercoasters and haunted houses communally. Stuffed animals and other mementos picked out in the virtual shopping square are printed out with the home 3D printer. Once it's time for a deserved break from all the adventures, meals ordered from the park can be delivered at home within 15 minutes by a nearby restaurant, as local restaurants have partnered with theme parks to create a lucrative side business that benefits their neighborhoods.

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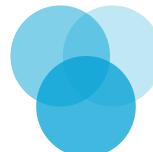
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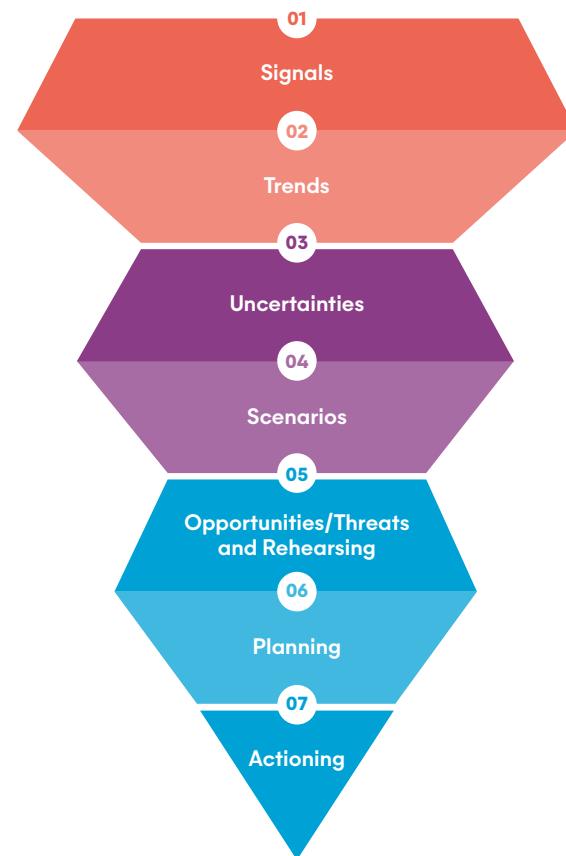
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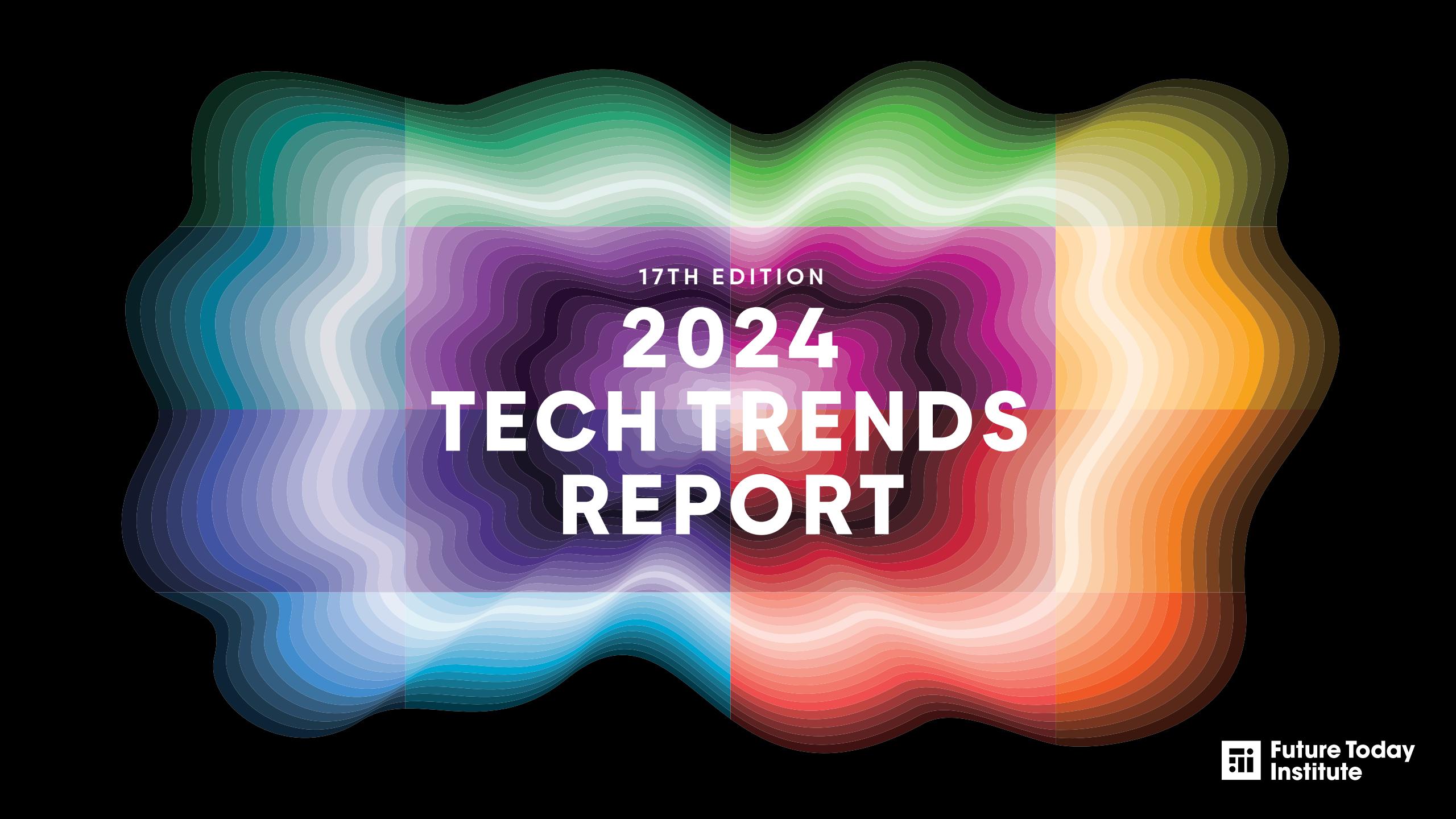
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