Platforms Of Innovation

How Converging Technologies Should Propel A Step Change In Economic Growth

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Introduction

I'd like to share with investors research about the world that we are about to inhabit, a world transformed by the convergence between and among technologies, the seeds of which were sown during the 20 years that ended at the turn of the millennium. ARK's analysts and I have been researching—discovering, understanding, and drawing inferences—from the way in which those seeds have germinated and are now flourishing.

Techno-economic discontinuity is a process whereby technological breakthroughs create sudden and unprecedented transformations. Such discontinuities occurred during the second industrial revolution after introductions of the internal combustion engine, electrification, and telephony. We believe that a similar, unprecedented technological boom is now underway.

Five major technological platforms are breaking new ground. Artificial Intelligence is permeating every sector and cognitive task, accelerating productivity across industries. Electric vehicles enabled by breakthroughs in Energy Storage are now as affordable as the average new gas-powered car. Robots like reusable rockets, drones, and sidewalk delivery vehicles are proliferating. Astounding advancements in Multiomics have pushed far beyond DNA, aligning genomic, epigenomic, transcriptomic, proteomic, and phenotypic information to unlock the codes of life, health, biological systems, and death. And Public Blockchains—spurred by the emergence and adoption of bitcoin—are primed to upend the monetary and financial landscape, wresting fundamental financial functions away from the traditional financial ecosystem.

This discontinuous set of changes has just begun.

Technological convergence is the process by which discrete technological capabilities coalesce and catalyze new ones. Emerging convergences should shape the next set of techno-economic discontinuities.

At ARK, we identify five innovation platforms—Public Blockchains, Multiomic Sequencing, Energy Storage, Robotics, and Artificial Intelligence—as the areas of technological foment creating the most meaningful convergences today. They are the emerging "general purpose technologies"[1] that we believe will transform and accelerate economic growth.

1 See Crafts 2004.

Five Converging Platforms Are Likely To Define This Technological Era

Public Blockchain

Upon large-scale adoption, all money and contracts will likely migrate onto Public Blockchains that enable and verify digital scarcity and proof of ownership. The financial ecosystem is likely to reconfigure to accommodate the rise of Cryptocurrencies and Smart Contracts. These technologies increase transparency, reduce the influence of capital and regulatory controls, and collapse contract execution costs. In such a world, Digital Wallets would become increasingly necessary as more assets become money-like, and corporations and consumers adapt to the new financial infrastructure. Corporate structures themselves may be called into question.

Artificial Intelligence

Computational systems and software that evolve with data can solve intractable problems, automate knowledge work, and accelerate technology's integration into every economic sector. The adoption of Neural Networks should prove more momentous than the introduction of the internet and potentially create 10s of trillion dollars of value. At scale these systems will require unprecedented computational resources, and AI-specific compute hardware should dominate the Next Gen Cloud datacenters that train and operate AI models. The potential for end-users is clear: a constellation of AI-driven Intelligent Devices that pervade people's lives, changing the way that they spend, work, and play. The adoption of artificial intelligence should transform every sector, impact every business, and catalyze every innovation platform.

Multiomic Sequencing

The cost to gather, sequence, and understand digital biological data is falling precipitously. Multiomic Technologies provide research scientists, therapeutic organizations and health platforms with unprecedented access to DNA, RNA, protein, and digital health data. Cancer care should transform with pan-cancer blood tests. Multiomic data should feed into novel Precision Therapies using emerging gene editing techniques that target and cure rare diseases and chronic conditions. Multiomics should unlock entirely new Programmable Biology capabilities, including the design and synthesis of novel biological constructs with applications across industries, particularly agriculture and food production.

Energy Storage

Declining costs of Advanced Battery Technology should cause an explosion in form factors, enabling Autonomous Mobility systems that collapse the cost of getting people and things from place to place. Electric drivetrain cost declines should unlock micro-mobility and aerial systems, including flying taxis, enabling business models that transform the landscape of cities. Autonomy should reduce the cost of taxi, delivery, and surveillance by an order of magnitude, enabling frictionless transport that could increase the velocity of e-commerce and make individual car ownership the exception rather than the rule. These innovations combined with large-scale stationary batteries should cause a transformation in energy, substituting electricity for liquid fuel and pushing generation infrastructure towards the edge of the network.

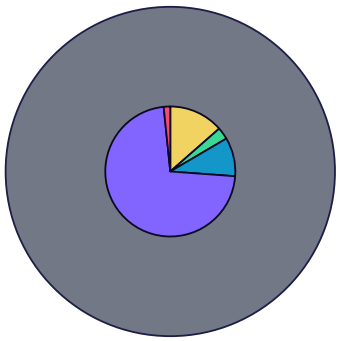
Robotics

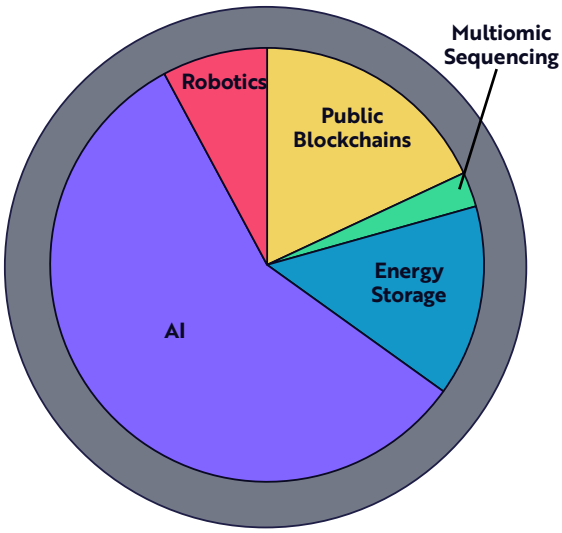
Catalyzed by artificial intelligence, Adaptive Robots can operate alongside humans and navigate legacy infrastructure, changing the way products are made and sold. 3D Printing should contribute to the digitization of manufacturing, increasing not only the performance and precision of end-use parts but also the resilience of supply chains. Meanwhile, the world's fastest robots, Reusable Rockets, should continue to reduce the cost of launching satellite constellations and enable uninterruptible connectivity. A nascent innovation platform, robotics could collapse the cost of distance with hypersonic travel, the cost of manufacturing complexity with 3D printers, and the cost of production with AI-guided robots.

Source: ARK Investment Management LLC, 2024. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security or cryptocurrency. Forecasts are inherently limited and cannot be relied upon.

Our research suggests that these five technology platforms are poised to converge, causing step changes in productivity and economic growth that could generate trillions of dollars in market value by 2030, as shown below. Together, they are likely to transform the techno-economic landscape more profoundly than did the second industrial revolution. Our modeling also suggests that these technologies will account for ~60% of all risk asset value[2] and generate most of the incremental appreciation in equity market capitalizations over the coming business cycle, as shown below. Importantly, because of the speed at which these changes are taking place, traditional benchmarks are unlikely to incorporate them in a timely way. Tesla, for example, did not earn its position in the S&P 500, in December of 2020, until it exceeded $600 billion in market cap—a 19x increase from its June 2019 low. As of this writing,[3] 8 of the companies in the S&P 500—less than 2% by number but accounting for more than 35% of its market cap—exceed $600 billion in market capitalization.

2023 Equity Market Cap Estimate		**2030 Equity Market Cap Forecast**		**Annual Growth Forecast**
Non-innovation	$98 trillion	Non-innovation	$140 trillion	3%
Disruptive innovation	$19 trillion	Disruptive innovation	$220 trillion	42%
Total	$117 trillion	Total	$360 trillion	17%





Artificial Intelligence 37%
Energy Storage 50%
Public Blockchains 48%
Robotics 78%
Multiomic Sequencing 39%

Source: ARK Investment Management LLC, 2024. This ARK analysis is based on a range of underlying sources, which are available upon request. Data as of 12/31/23. For underlying assumptions and methodologies please refer to Convergent Capabilities Tables on pp. 33-37. [["14 Convergent Capabilities In The Year 2030"]] in section III. The annual growth rates reflect ARK's forecasted compound annual growth rate for each technology platform. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security or cryptocurrency.

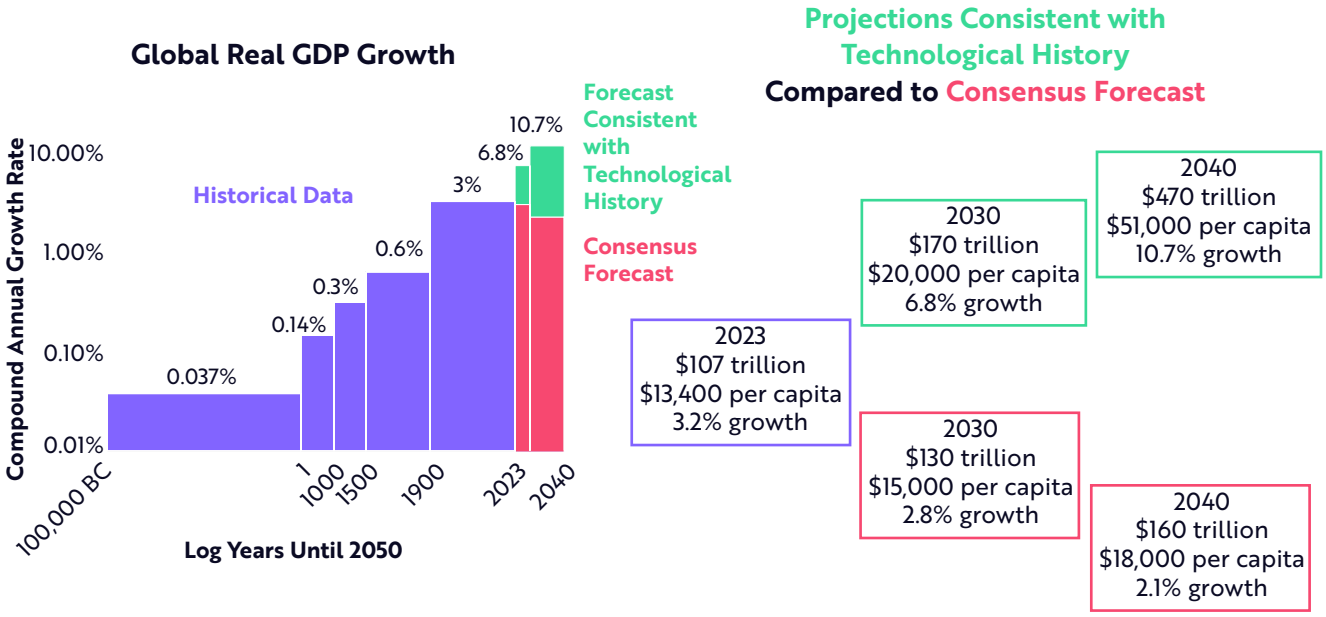
2 *Here we define risk assets by adding prospective public blockchain value to equity market capitalization.*
3 *March 20, 2024.*

In this paper, I discuss the dynamics of convergence and techno-economic discontinuity:

- **Section I** elaborates on ARK's forecast for the Economic Impact of Converging Technologies during the next two decades, a period of unprecedented growth that is likely to align with techno-economic patterns historically.
- **Section II** presents How We Measure Convergence. We detail the convergence scoring framework that we use to quantify the importance of each technology as a catalyst, as well as each technology's dependence on other technological advances. We illustrate this scoring framework with a series of case studies.
- **Section III** presents 14 Future Convergence Scenarios, highlighting the technologically enabled transformations that we believe will be realities by 2030.
- **Section IV**, our Conclusion, offers some closing thoughts on our economic forecasts.

SECTION I: The Economic Impact Of Converging Technologies

In our view, technological convergences across five innovation platforms will unlock a discontinuous step change in annualized economic growth over the coming business cycle. Our view differs substantially from consensus expectations.[4] How? Let's look at the data in the chart below.



Sources: ARK Investment Management LLC, 2024, based on data from Bolt et al. 2022; Nalley et al. 2021; DeLong 1998; The World Bank Group, as of 01/27/23. Numbers are rounded. Consensus forecast is the reference economic case for the EIA's International Energy Outlook. X-axis of log years until 2050 is tuned to the best fit against the historical data. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security or cryptocurrency. Past performance is not indicative of future results.

4 *For a more extensive treatise on economic super-exponential growth and how artificial intelligence may change the underlying rate of growth, please see Davidson 2023, which serves as inspiration for much in this section.*

The purple bars indicate historical annual growth rates in real terms. The red bar represents the U.S. Energy Information Administration's (EIA's) long-run forecast of real growth in global Gross Domestic Product (GDP) and is consistent with that of other economic forecasting agencies. The green extension of the red bar denotes ARK's long-run real GDP growth expectation, including global GDP more than 3x higher in real terms than the EIA's estimate in 2040.

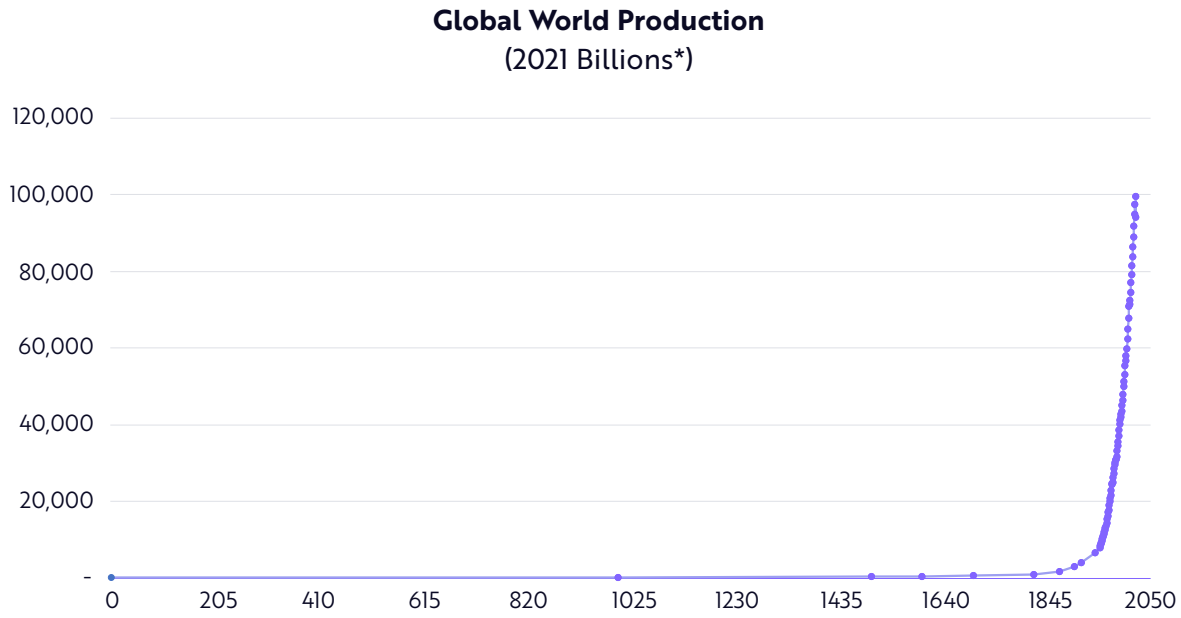
Looking closely at the red bar, we see that traditional forecasters expect real GDP to reach $130 trillion in 2030 and $160 trillion by 2040—or $15,000 and $18,000 per capita, respectively. Interestingly, they expect the global growth rate to decay consistently over the next two decades.

In contrast, thanks to technologically enabled disruptive innovation, we believe that real GDP growth will accelerate. If we are correct, real GDP could reach $170 trillion and $470 trillion globally in 2030 and 2040, respectively, as illustrated by the green bar, with 2030 per capita GDP 33% higher in real terms than consensus expectations.

Two strands of ARK's research drive our outsized GDP growth expectations . The first is our deep exploration of the way in which we believe converging technological innovations and their cost declines will create market value. The second is our appreciation for long-term tech-economic history, an empirical approach that does not seem to inform the traditional consensus forecasts.

Let's look back at the progression of economic growth throughout history relative to expectations for the future. The purple bars in the chart above capture the compounding progress of innovation throughout techno-economic history from 100,000BC to 2023. Illustrated by the green bar is ARK's expectation for real global growth, resulting in a world economy ~3x larger than the consensus forecast in 2040.

Informing ARK's optimism about future economic growth are patterns from the past: over long time periods, sudden and dramatic changes in the rate of economic growth—step function changes—have been the rule, not the exception. To illustrate, let's explore the purple bars from another perspective, as shown below.



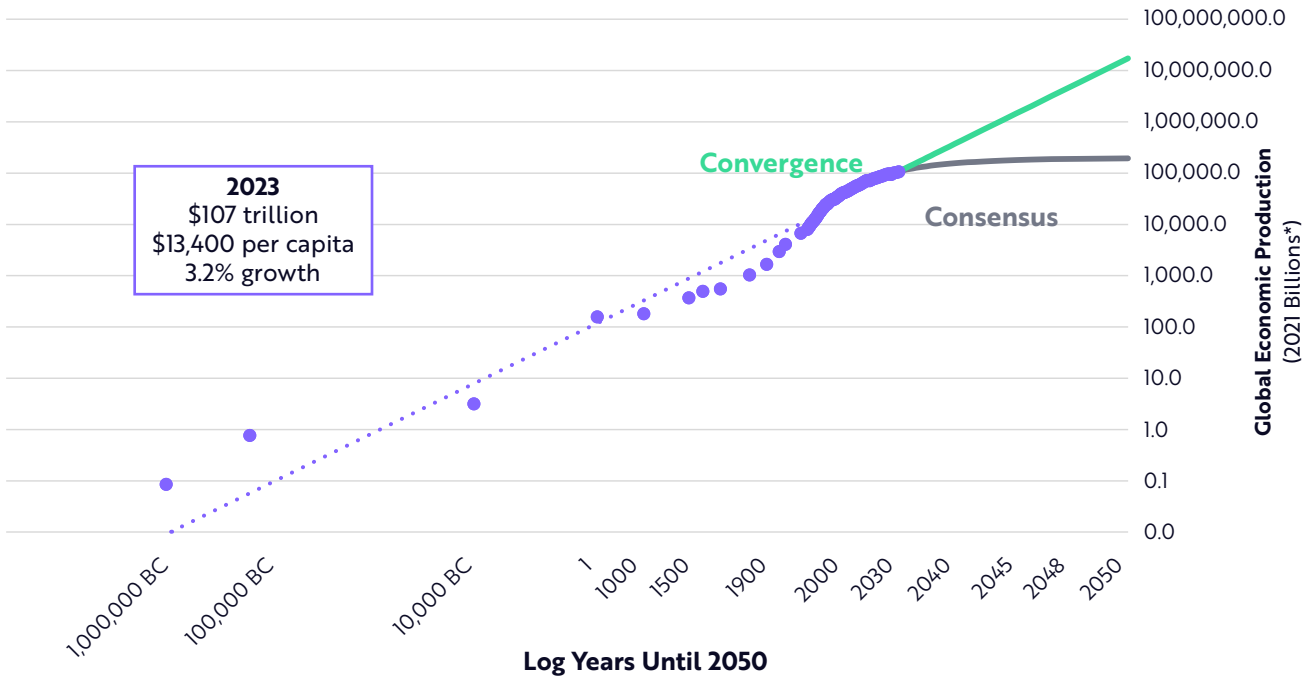
** Note: All dollar amounts are inflation adjusted to 2021 levels. Source: ARK Investment Management LLC, 2024. Data prior to 1990 are backward-extended from The World Bank observation for 1990, based on growth rates implied by Maddison Historical Statistics 2022. Data from 1990 onward are sourced from The World Bank. 2022. All data accessed as of 9/16/22. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security or cryptocurrency. Past performance is not indicative of future results.*

Prior to the discovery and proliferation of writing, the global economy was anemic, with growth rates below 0.04% in the 100,000 years prior to the rise of Rome. In the first 1,000 years AD, annual growth accelerated nearly four-fold to 0.14%. Then, plow technology and crop rotation strategies led to a population boom, more than doubling growth to 0.3% at an annual rate through 1500.

The printing press and the steam engine bookended the first industrial revolution, doubling growth again to 0.6% per year through 1900. Thereafter, electrification, telephony, the internal combustion engine, and digital computation and connectivity quintupled real economic growth to 3% at a compound annual rate, pushing global GDP to $107 trillion. As a result, global real per capita GDP has increased nearly 7-fold since 1900 from less than $2,000 to more than $13,400 in 2023.

Shown below is another illustration of the trajectory of production, suggesting that our forecast is consistent with historical patterns.

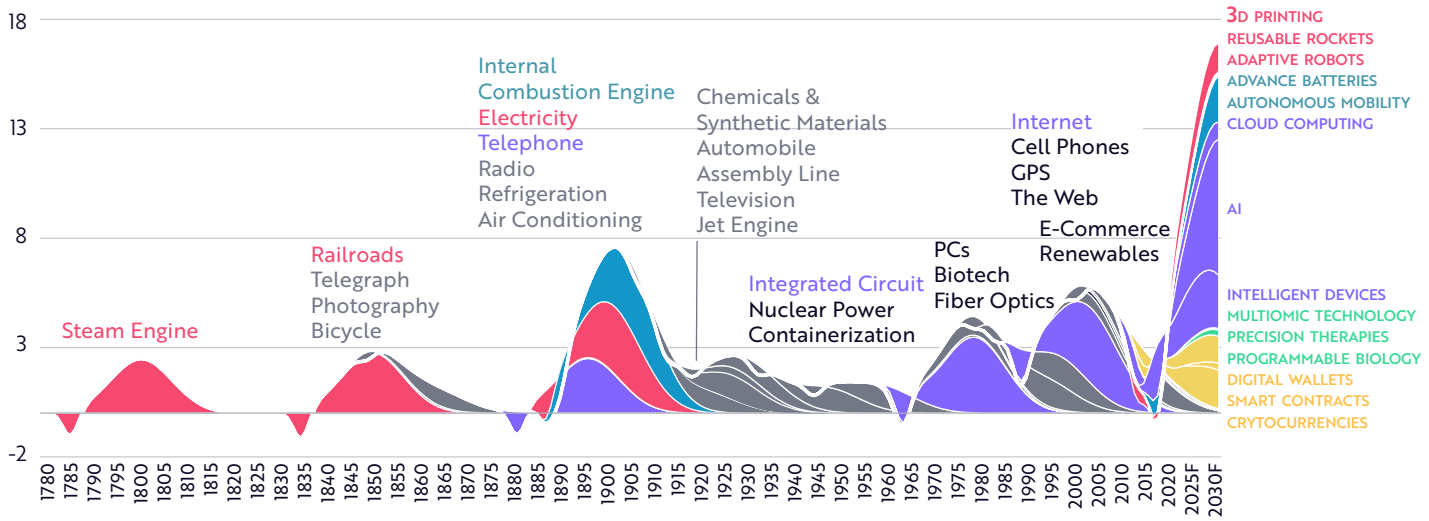
Could We Experience Another Step Change in Growth?
(Or are all of the economically meaningful innovations in the past?)



**Note: All dollar amounts are inflation adjusted to 2021 levels. Source: ARK Investment Management LLC, 2024. Data prior to 1990 are backward-extended from The World Bank observation for 1990, based on growth rates implied by Maddison Historical Statistics 2022. Data from 1990 onward are sourced from The World Bank 2022; Nalley et al. 2021; Delong 1998. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security or cryptocurrency. Past performance is not indicative of future results.*

The purple datapoints refer to global GDP at various points in time. The purple line shows the regression across all datapoints. Scaled on the log-year difference until 2050, the x-axis produces the cleanest regression against the known data. As depicted by the green line, the forecast is consistent with techno-economic history and indicates that step changes, or discontinuous changes, have taken place more frequently over time. The gray line depicts a consensus economic forecast like that of the EIA, suggesting that a 100,000-year uptrend is sputtering out as innovation asymptotes. By contrast, in ARK's view, the impressive 100,000-year super-exponential trend will continue apace, sustained—if not turbocharged—by the provocative convergence among innovation platforms in force today, as shown below.

Estimated Economic Impact Of General Purpose Technologies
(Rough Annual Percentage Point Additions to the Economy, inclusive of consumer surplus)

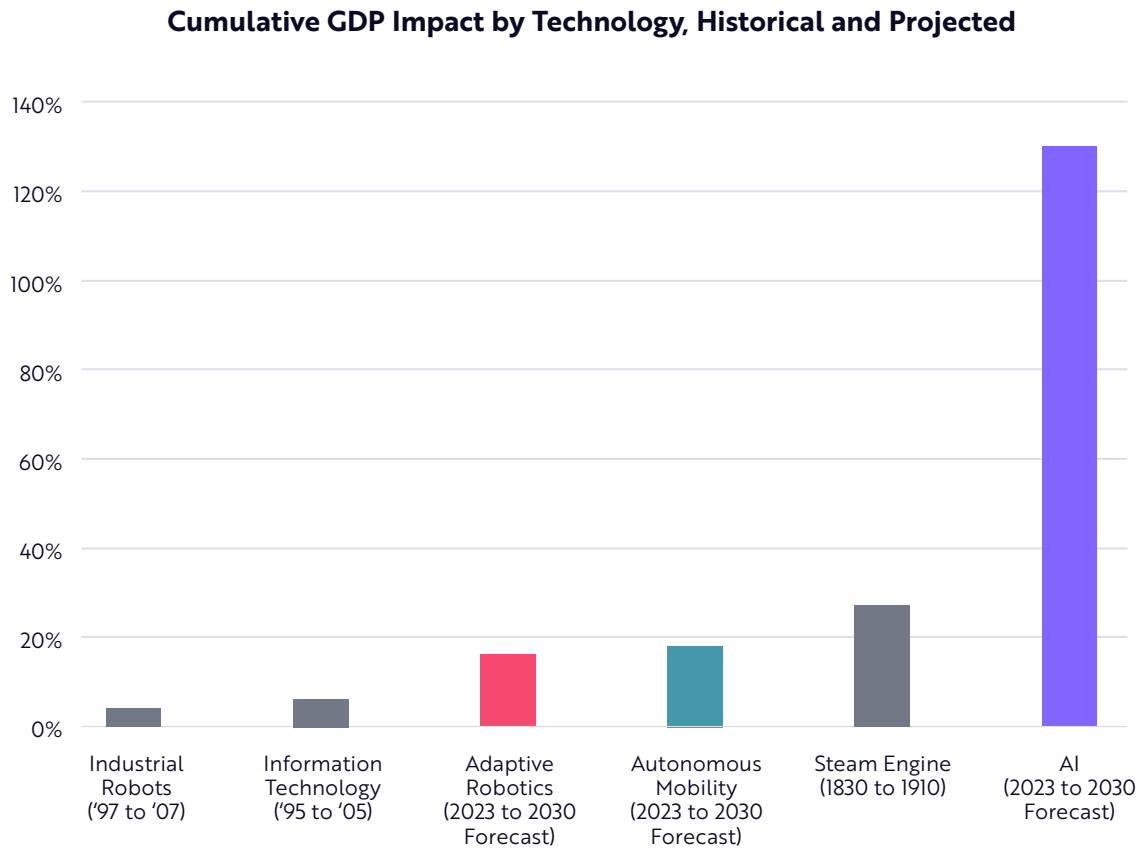


Source: ARK Investment Management LLC, 2024. This ARK analysis is based on a range of underlying sources, which are available upon request. Data as of December 5, 2023.[5] Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security or cryptocurrency. Past performance is not indicative of future results.

The gray data in the chart above present the estimated historical economic impact of all general purpose technologies.[5] The colored data present our estimates of the economic impact of the prospective general purpose technologies that we identify. We believe that by the end of the decade the annual economic impact of today's converging technologies will roughly double the economic impact of those technologies that triggered the second industrial revolution at the turn of the 20th century.

Indeed, our modeling suggests that neural networks will catalyze a range of technology offerings, each of which independently could qualify as amongst the most economically meaningful in history. We believe that the economic impact of adaptive robots, autonomous mobility devices, and AI software will each compare favorably with the steam engine—the triggering technology for the first industrial revolution. The market impact should be even more dramatic: while the steam engine transformed the British economy over 80 years, neural networks and AI software could impact every facet of global activity over the course of this decade, as shown below.

5 *We use GPT 4 prompting to survey a comprehensive list of general purpose technologies using the identification framework detailed in https://core.ac.uk/download/pdf/85004244.pdf. Where available, we sample academic literature to assess attributable economic impact. We feed GPT-4 a scoring rubric to assess technology-by-technology impacts. The directly measured impact is matched against the scoring to tune all scores to produce technology-by-technology estimates of economic impact (even when direct measures of economic impact are unattainable). Consistent with GPT theory, these technologies are assumed to go through a period of investment where economic impact is negative before productivity advances begin to realize into economic data. A more complete detailing of this methodology is forthcom*



Source: ARK Investment Management LLC, 2024. Based on data from Crafts 2004; McKinsey Global Institute 2017; O'Mahoney and Timmer 2009. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security or cryptocurrency. Past performance is not indicative of future results.

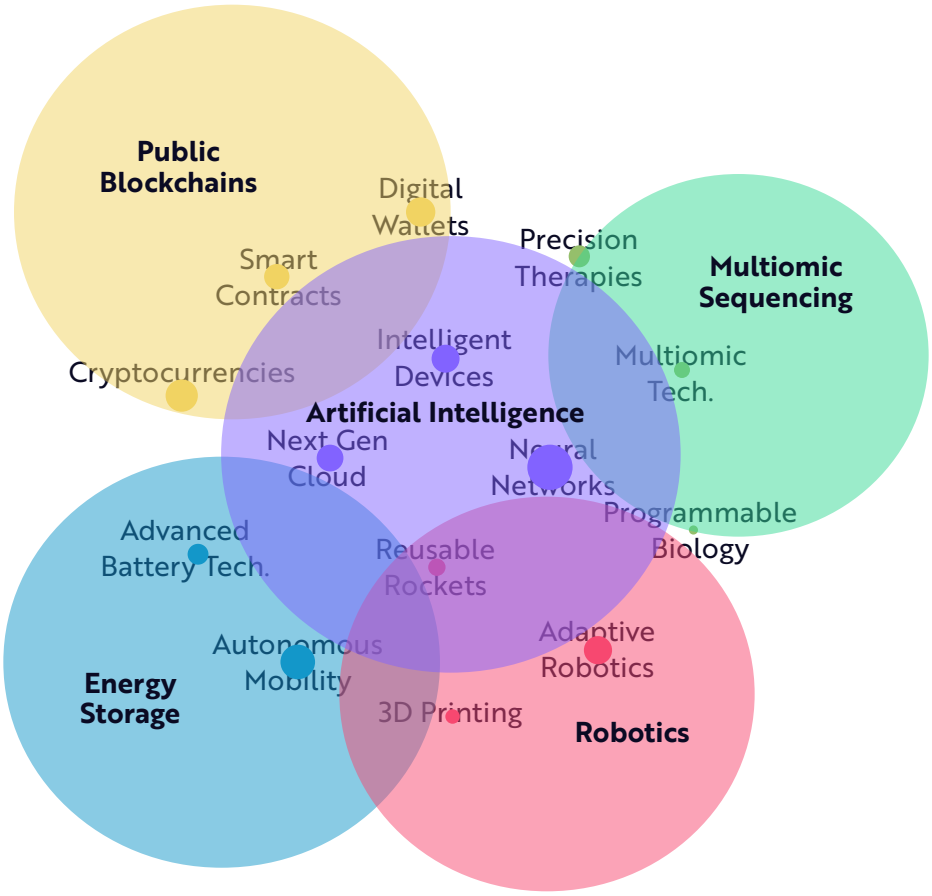
SECTION II: How We Measure Convergence

While history informs ARK's research, our forecasts are not based on past trajectories. Indeed, the regression-based forecast shown in the "Estimated Economic Impact of General Purpose Technologies" chart above is sensitive to a sparse set of data points that predate the 20th century, and minor changes to the x-axis could slow the expected timing for a next inflection in economic growth meaningfully.

Consequently, we triangulate our understanding of history with our understanding of the technologies themselves. There is on-the-ground evidence that convergence between and among technologies drives their coincident acceleration. Our forecasts suggest that these are the earliest indications of a tremendous technological blossoming. The technologies that we study are becoming increasingly interconnected such that an acceleration in one leads to an acceleration

in all. As a result, multiple technological waves are being pulled into resonance and will stack one atop the other. On this basis, technological growth will beget technological growth, and we believe the world will experience an unprecedented transformation extending through this decade and beyond.

To understand the technical potential of the five major innovation platforms evolving today—Public Blockchains, Multiomic Sequencing, Energy Storage, Robotics, and Artificial Intelligence—we have delineated them into distinct technologies—14 in all—as shown below.



Source: ARK Investment Management LLC, 2024. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security or cryptocurrency.

Each of these 14 technologies meets criteria that identify General Purpose Technologies associated with major technological shifts. Among them:

- Each follows a steep learning curve characterized either by falling costs or by better performance at the same cost.

- Each cuts across economic sectors, expanding access and creating mass market opportunities.
- Each serves as a launching pad for new and complementary technologies.

Each of the 14 technologies is investable today. We forecast the future business value for each technology by modeling unit economics cases for different end buyers along anticipated cost decline curves. This research bolsters our confidence in the likelihood of a step-change in the rate of macroeconomic growth.

Capital markets tend to focus on individual technologies and highlight those dominating headlines—like artificial intelligence today. In our view, acceleration in one technology ultimately leads to acceleration in all, such that diffusion curves forming in multiple domains build one upon the other, catapulting growth to unprecedented heights.

In this section, we offer investors an overview of some of our research on converging technologies, focusing on the potential for cross-sector catalyzation and future demand.

» The first sub-section describes ARK's convergence scoring framework, which measures each technology's sensitivity to all other technologies' advances.

» The second sub-section presents three ARK Convergence Case Studies and highlights some of ARK's research on neural networks, describing how:
  - Neural Networks Catalyze Advances in Autonomous Mobility
  - Neural Networks Catalyze Advances in Multiomic Technologies
  - Neural Networks Catalyze Advances in Robotics

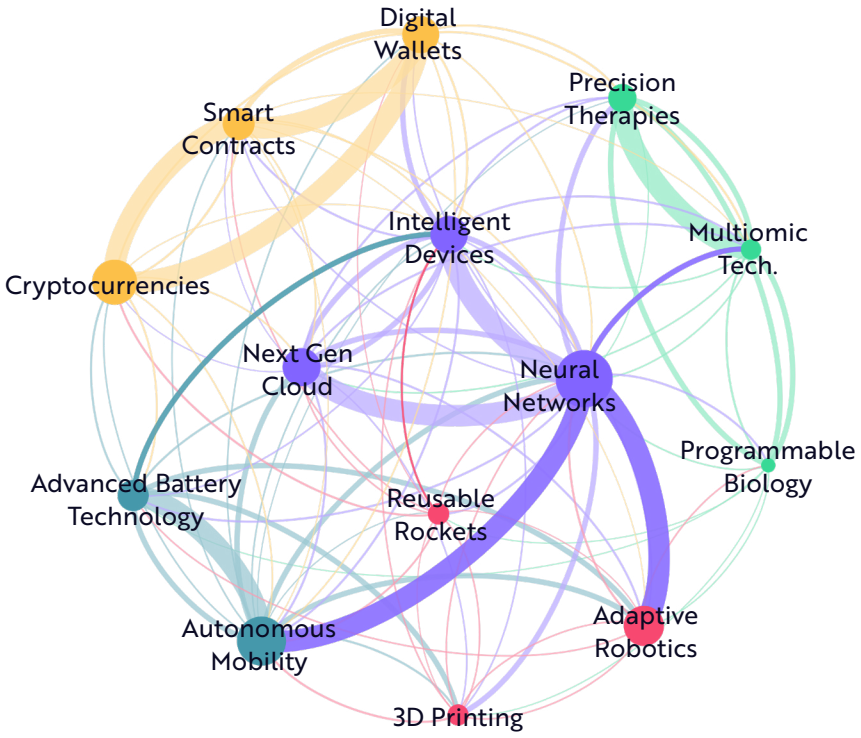
» The third sub-section presents three ARK Convergence Case Studies and highlights ARK's research on Advanced Battery Technologies, Intelligent Devices, Reusable Rockets, and Cryptocurrency. Here we describe how:
  - Advanced Battery Technology Catalyzes Advances in Intelligent Devices
  - Reusable Rockets Catalyze Advances in Intelligent Devices
  - Cryptocurrency Catalyzes Advances in Battery Systems

» We close this section in subsection four with a discussion of how ARK's Convergence Scoring Framework may be inverted to gauge a technology's sensitivity to other technological advances.

1. ARK's Convergence Scoring Framework

Each of the 14 technologies has well-documented metrics that measure its fundamental characteristics. We use Wright's Law[6] to measure and forecast cost declines, and we derive unit economics by anticipating the price-elasticity of demand as a technology scales across sectors. To determine if a technology is a robust innovation platform, we have developed a Convergence Scoring Framework that measures the potential of each technology as a catalyst for more innovation.

Shown in the chart below is a visualization of ARK's Convergence Scoring Framework across the 14 technologies. We color-coded nodes by their major innovation platform, and we scale the weight of interconnection by the degree to which one technology serves as a meaningful catalyst for another. This network graph reinforces the validity of our innovation platform taxonomy: although we scored convergence at the technology level, those making up the same innovation platforms are more highly interconnected; the spatial clustering of each innovation platform in this network visualization emerges organically as a result of those interconnections.



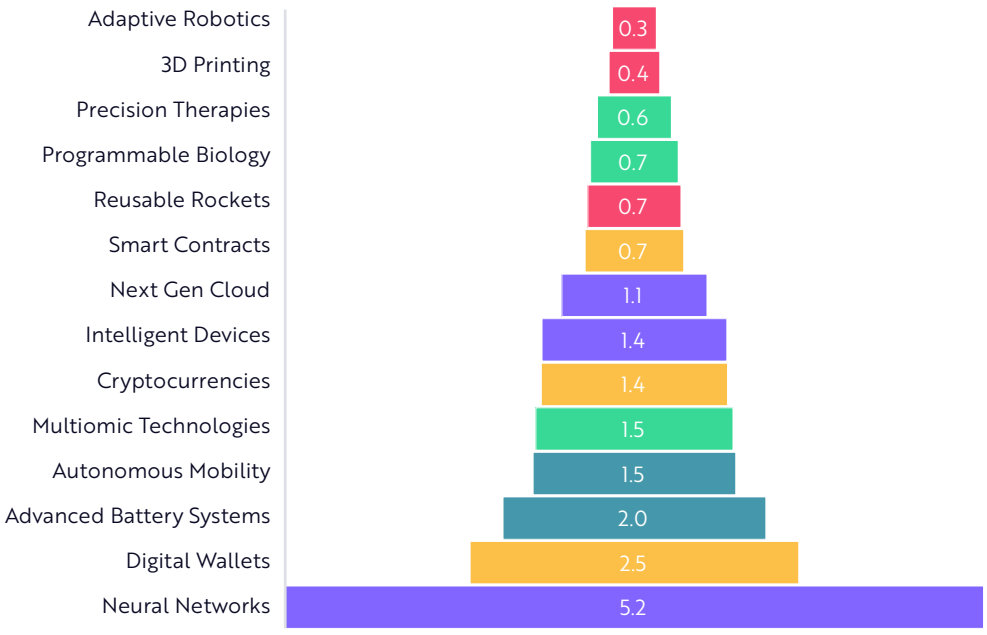
Source: ARK Investment Management LLC, 2024. Node size is log-proportional to anticipated 2030 market capitalization by technology. Nodes are colored according to the innovation platform that the technologies gross up. Edges are directional with thickness proportional to degree the technology is a catalyst for the connecting technology and color coded by the catalyzing technology. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security or cryptocurrency.

6 *The relationship between investment in company operations and profitability is a critical component of our financial models, led by Wright's law, which focuses on the cost declines associated with unit production. Specifically, for every cumulative doubling of units produced, costs will fall by a constant percentage. Wright's law lays the foundation for decreasing costs as company production ramps. See Winton 2019.*

We use convergence scoring to understand the degree to which advances in one technology increase the potential value of another technology—they are directionally scored. For example, the high value accrual impact of neural networks on multiomics technology is scored independently of the lower value accrual impact of multiomics technology on neural nets.[7] As can be seen in the foldout table on the following page, the highest scoring convergences anticipate that advances in one technology will increase the value of another technology by an order of magnitude or more. The scoring rubric scales down in semi-log fashion from there: the second highest category of convergence anticipates an increase in another technology's value by multiples, while in the lowest category value accrual may well be non-material. The foldout table on the following page details the methodology and justifications for convergence scores between each technology pair.

By aggregating convergence scores, we can measure the overall importance of each technological catalyst, which captures the degree to which a single technology is responsible for value accrual expectations in all the other technologies that it catalyzes. As shown below, neural networks are far and away the most important catalyst. The scoring is scaled and aggregated such that a "1" could mean that a technology is responsible for catalyzing a 10x value accrual in a single other technology, a 5x accrual across two technologies, or a 2x accrual across 5 technologies (or any other mathematical combination).

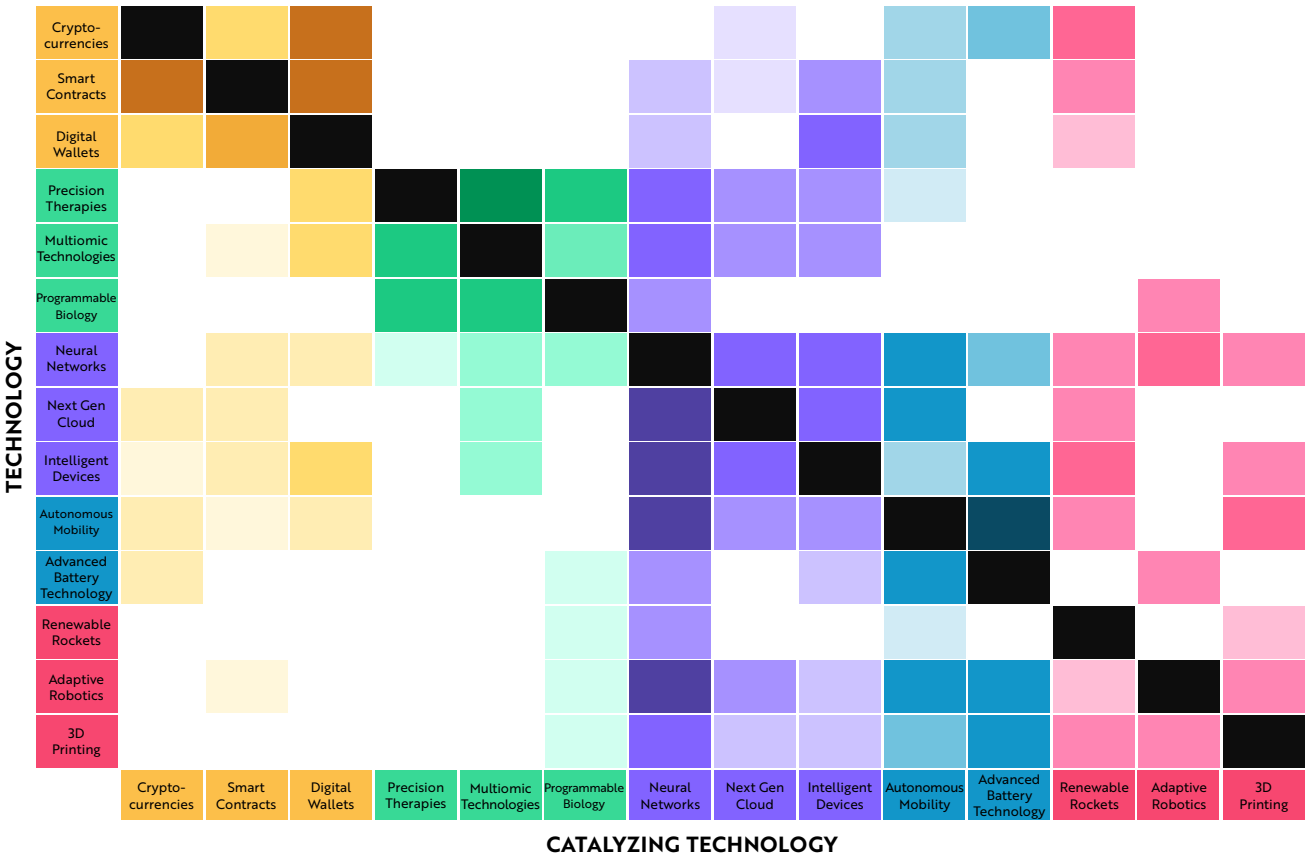
Importance as a Catalyzing Technology



Source: ARK Investment Management LLC, 2024. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security or cryptocurrency.

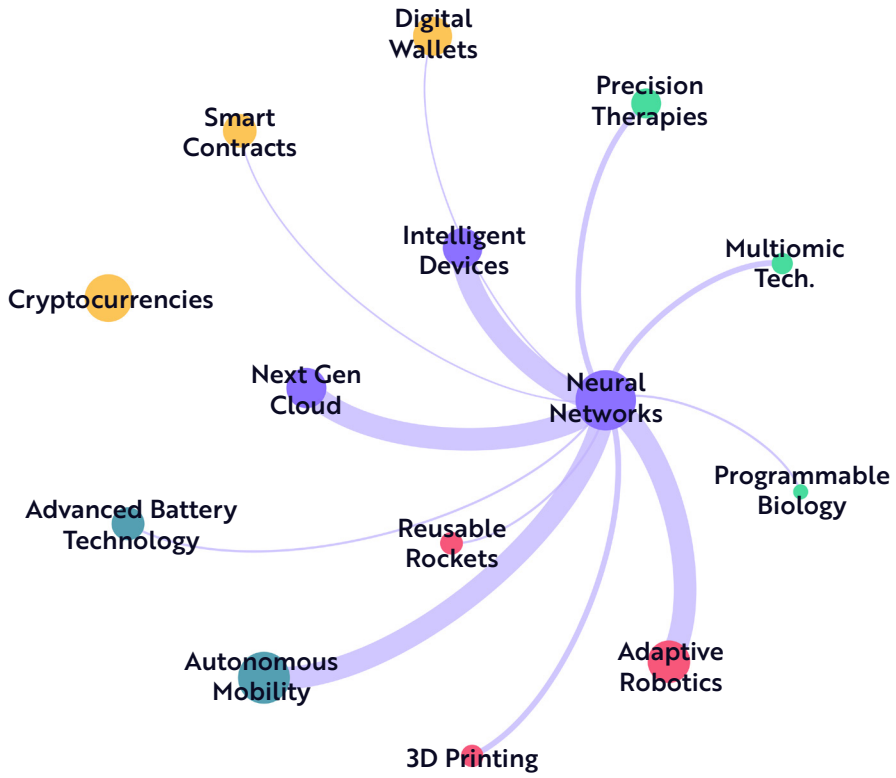
7 *These scores are relative to the overall opportunity for the technology. Multiomic technology scores low as a catalyst for neural networ in part because the value accrual opportunity for neural networks is so broad that the marginal impact of multiomic data is likely to b relatively minor.*

This Technological Convergence Matrix Illustrates The Relationships Between And Among Catalyst



More detailed version of this graphic, including detailed scoring information and justification available here. Sources: ARK Investment Management LLC, 2024. This ARK analysis is based on a range of underlying data from external sources, which may be provided upon request. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security. Past performance is not indicative of future results.

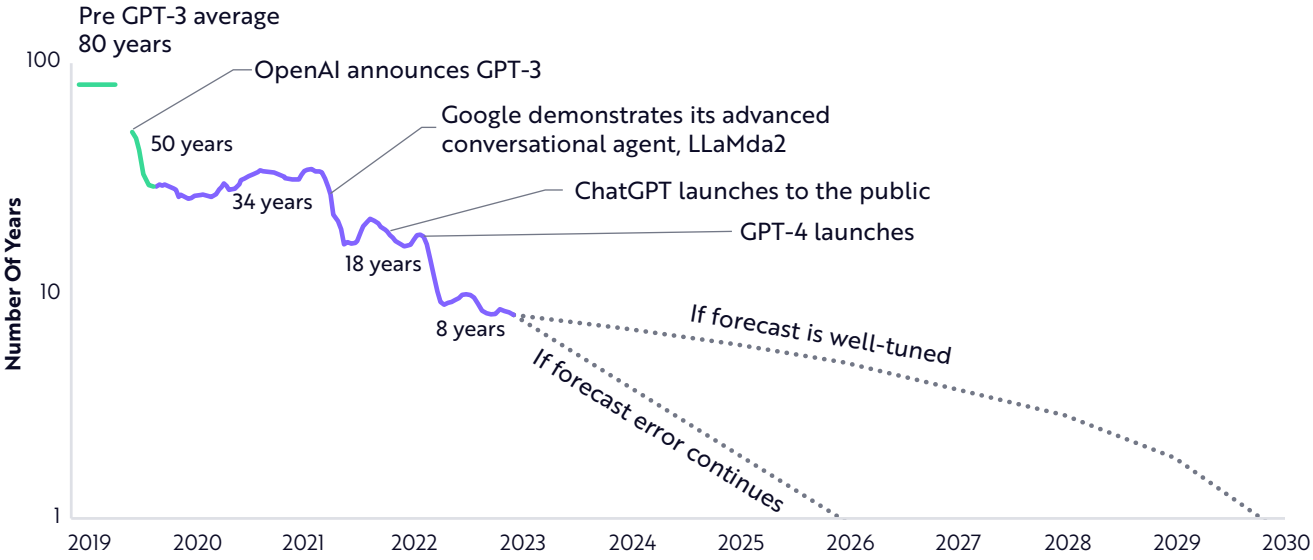
Neural networks score a bit more than 5 on this aggregate measure, with the highest degree of convergence with Intelligent Devices, Next Gen Cloud, Adaptive Robots and Autonomous Mobility systems, from which 4 points of this score derive, as shown below. The remainder comes from the sum of neural network convergences with nearly every other technology we study. In many cases—even in these lesser convergences—we expect neural networks to catalyze an increase in value of 2 or more times.



Source: ARK Investment Management LLC, 2024. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security or cryptocurrency.

The aggregate convergence scoring indicates that an acceleration in neural networks would have the most meaningful impact on our overall value accrual expectations. Evidence suggests that neural networks are accelerating more quickly than many expected. The graph below shows competitive forecasters' expectations for the time it would take an Artificial General Intelligence (AGI) system to become available. If expectations were well-tuned, the estimates would decline gradually; but the capabilities of product releases clearly are catching forecasters off guard. Expected time to AGI fell from 3 decades in 2021, to 18 years in 2022, to less than a decade after the release of GPT-4. Using forecasters' expectations on a weaker benchmark, we estimate that prior to the mid-2020 release of GPT-3, forecasters would have thought that AGI was more than 80 years away! The future is coming much faster than anyone could have anticipated, in other words, and an acceleration in AI should pull forward almost every technology that we study.

Expected Years Until A General Artificial Intelligence System Becomes Available
(Log Scale)



Source: ARK Investment Management LLC, 2024. Based on data from Metaculus 2023, as of November 10, 2023. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security or cryptocurrency. Past performance is not indicative of future results.

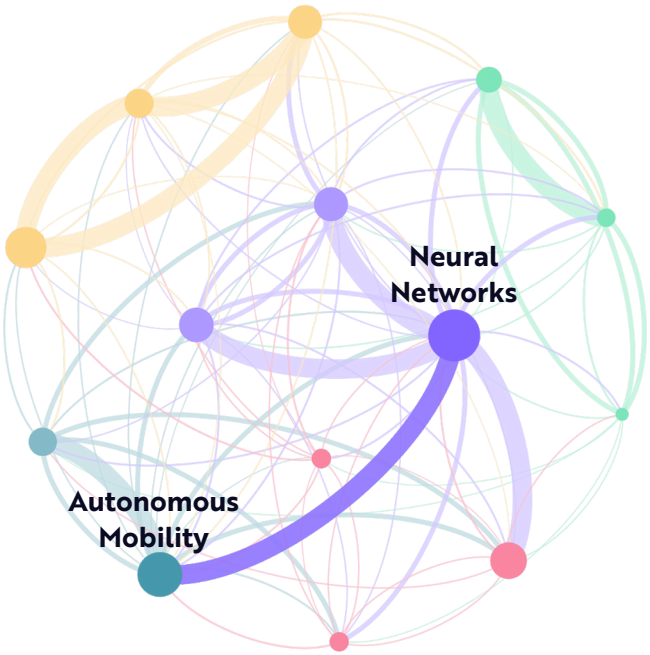
2. ARK Convergence Case Studies: Neural Networks Converging with Autonomous Mobility, Multiomic Technologies, and Adaptive Robotics

This sub-section presents a sample of our research on the ways in which neural networks will catalyze advances in autonomous mobility, multiomic technologies, and adaptive robotics.

Convergence Case Study 1: Neural Networks As A Catalyst For Autonomous Mobility

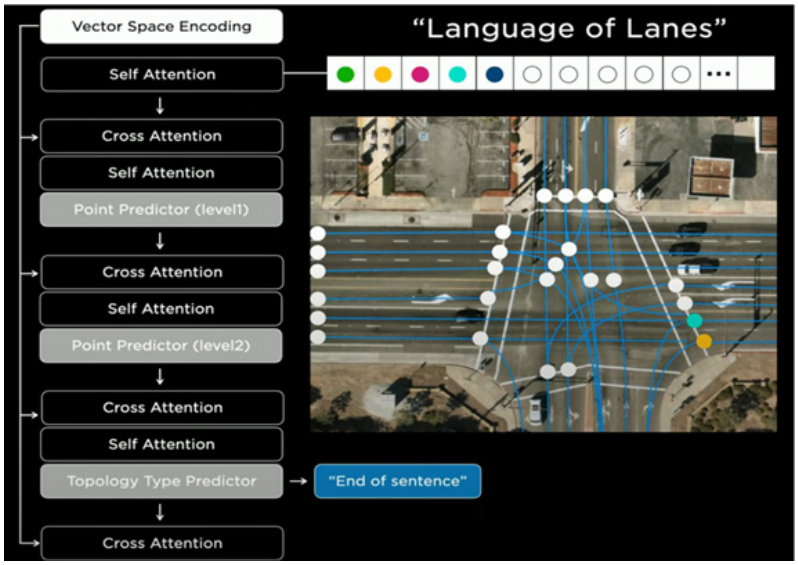
Convergence: Highest

Advances in natural language AI are increasing the capability of robotaxis. Neural networks should increase the total addressable market of autonomous mobility by ten-fold or more.



Source: ARK Investment Management LLC, 2024. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security or cryptocurrency.

Put simply, advances in the large language models that have captured the world's attention translate directly into advances in autonomous mobility software. For example, Tesla's Full-Self-Driving (FSD) system understands intersections by relying on the same transformer architecture that enables GPT-4 and other language models.



Source: Chen 2022. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security or cryptocurrency.

Further, Tesla is incorporating not only state-of-the-art image generation diffusion models to process data from its cameras but also reinforcement learning—once thought a dead-end for neural network capability but now used to train ChatGPT—to develop its autonomous taxi system. In other words, advances in state-of-the-art neural networks are increasing the capability and scalability of Tesla's autonomous mobility systems.

Developed originally for language translation, the transformer architecture now can help robotaxis navigate intersections. Likewise, developed originally to translate text into images, diffusion models[8] have become essential to autonomous driving.

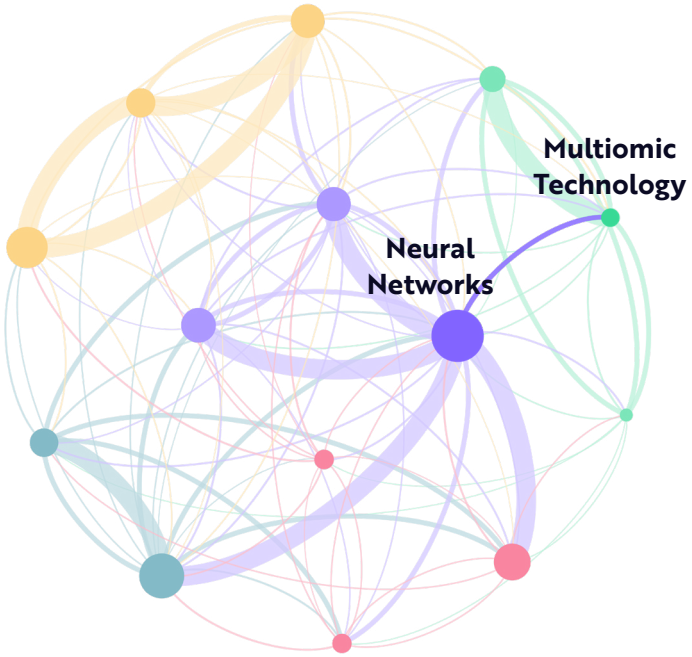
From this case study, we conclude that novel neural network architectures and techniques in software built for particular use cases could apply to other domains. According to our research, neural net performance per dollar spent is likely to improve 4x per year, increasing the likelihood that robotaxi networks will reach scale and generate the ~$30 trillion in enterprise value that we anticipate.[9]

Convergence Case Study 2: Neural Networks As A Catalyst For Multiomic Technologies

Convergence Score: High

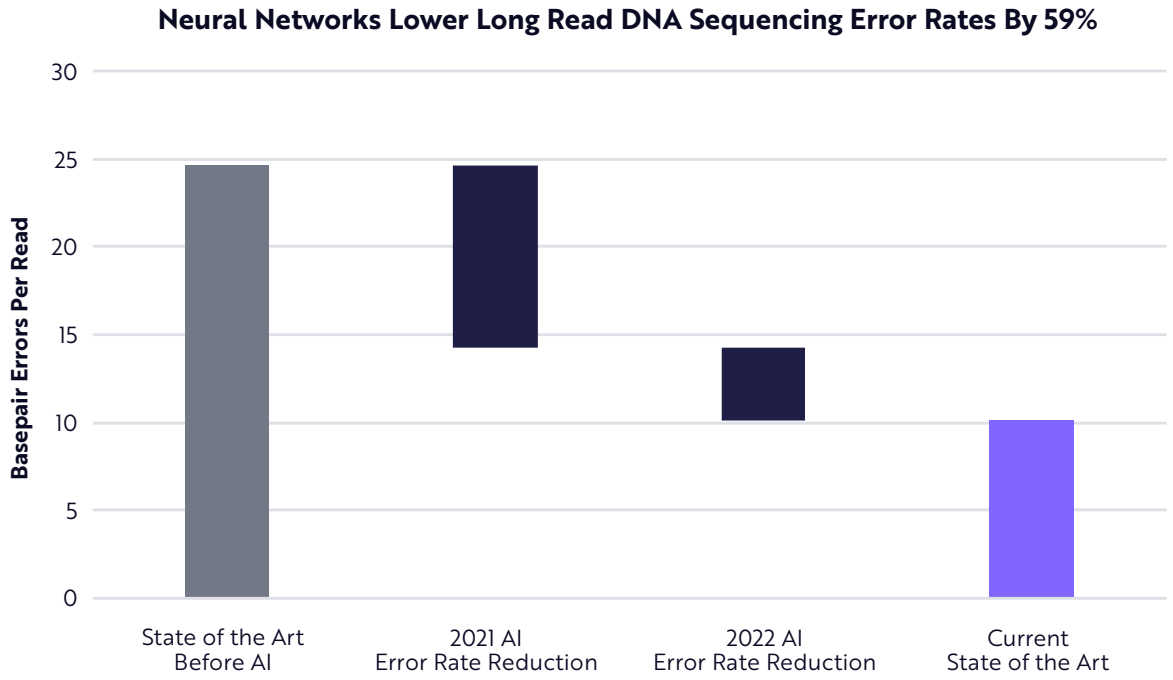
New transformer architectures also apply in health care, specifically DNA sequencing to identify mutations—or programming errors—in the human genome. Sequencing long DNA fragments is critical to detecting structural variations in the genome, but long-read sequencing machines have high error rates in reading single-nucleotides relative to their short-read peers. In 2021, Google researchers applied the transformer architecture used in language generation models to long-read DNA sequencing data generated by Pacific Biosciences' Sequel II sequencing machine. Neural networks should enable multiomics technologies to diagnose cancer in—if not before—Stage 1, increasing the value that accrues to multiomic technology providers by multiples.

8 *Wikipedia. NDa.*
9 *ARK Investment Management 2024*



Source: ARK Investment Management LLC, 2024. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security or cryptocurrency.

Even without changes in the underlying hardware, neural networks reduced long-read DNA sequencing error rates by 59% in fewer than two years,[10] transforming the Sequel II system's economics, as shown below.



Source: ARK Investment Management LLC, 2024. Based on data from Carol 2022; Gaid et al. 2022, as of 2022. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security or cryptocurrency.

10 Carrol 2022.

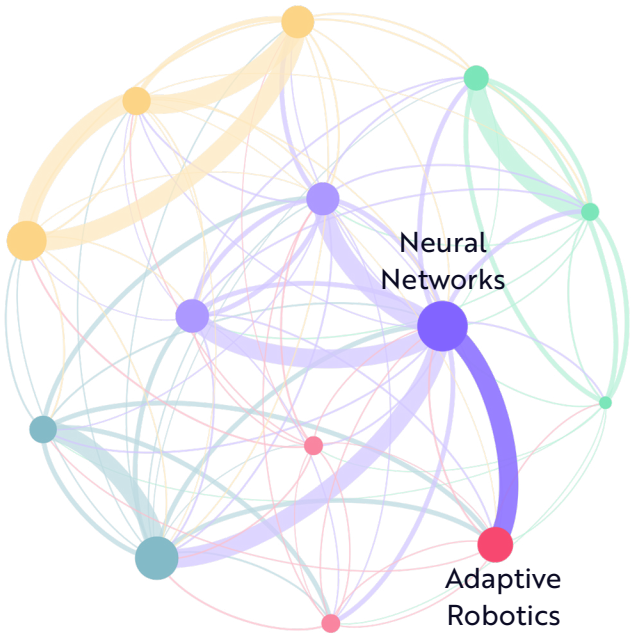
Now, for the same sequencing cost, researchers have roughly doubled the collection of data that is 99.9% accurate.[11] In effect, an AI software update nearly halved long-read sequencing costs. To take advantage of these capabilities, PacBio has incorporated an AI acceleration chip into its next-generation Revio system.

From the PacBio case, we infer that many hardware companies will be able to unleash neural networks to improve performance. Every hardware system that generates complex data, even those already in use, has the potential to be improved by AI, potentially creating virtuous flywheels in which more powerful devices generate more data and more revenue that, reinvested, can improve the AI software and, then again, the device.

Convergence Case Study 3: Neural Networks As A Catalyst For Adaptive Robotics

Convergence score: Highest

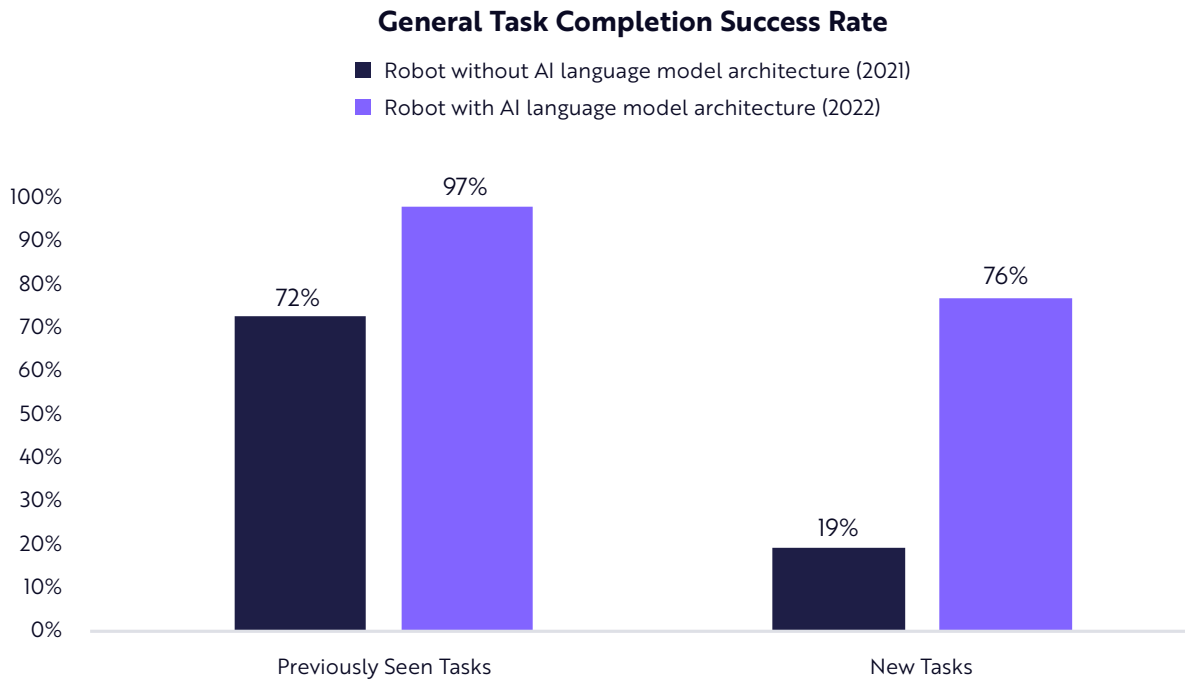
A robot that can speak and understand natural language instructions is more useful than one that cannot. Less obvious, though critical to understanding how closely AI and robotics are entwined, the same architectural advances in AI models that enable natural language understanding also can increase robotic capabilities. Neural networks should increase the total addressable market of adaptive robotics systems by an order of magnitude or more, as illustrated below.



Source: ARK Investment Management LLC, 2024. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security or cryptocurrency.

11 Google AI. 2023.

Google researchers demonstrated the neural network-robotics convergence when they trained an AI model not on written material, but on robotic images, actions, and explanations of the task. When compared with previous state-of-the-art robotics, the transformer-based architecture—known as RT-1, or Robotics Transformer 1—improved success rates significantly. Researchers required the robots to navigate unstructured kitchen environments and perform typical kitchen tasks—"pick the rice chip bag from the middle drawer and place it on the counter" or "place the coke can upright." Robots had seen explicit examples in some cases but not in others. The transformer architecture impacted both positively, as shown below.



Source: ARK Investment Management LLC, 2024, based on data from Gopalakrishnan et al. 2022; Brohan et al. 2022; Jang et al. 2022. Compares performance of RT-1, the robotics transformer architecture to BC-Z, based on a recurrent neural net architecture. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security or cryptocurrency. Past performance is not indicative of future results.

On known tasks, RT-1 reduced robot failure rates from ~30% to ~3% but, even on novel tasks, success rates improved from less than 20% to ~75%. While a 75% success rate is not good enough in many contexts, the improvement from 19% based on an AI software upgrade suggests that neural networks should be able to bend the robotics performance curve. Currently, the robotics market is dominated by automation systems inside steel cages operating on factory lines, but advances in neural networks should set them free.

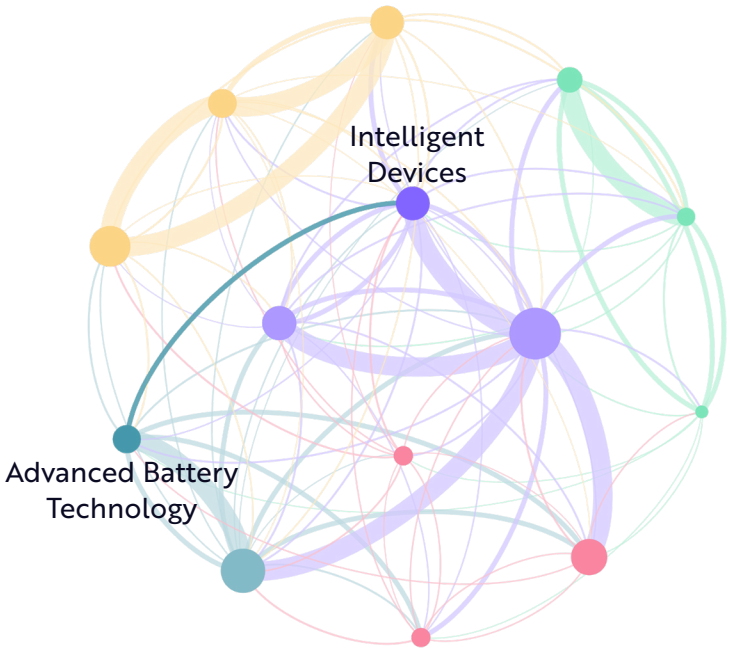
3. ARK Convergence Case Studies: Advanced Battery Technology, Reusable Rockets, and Cryptocurrency

The promises of convergence go beyond those associated with neural networks. The following case studies illustrate how other technologies likely will serve as catalysts for expanding market potential.

Convergence Case Study 4: Advanced Battery Technology as a Catalyst for Intelligent Devices

Convergence score: High

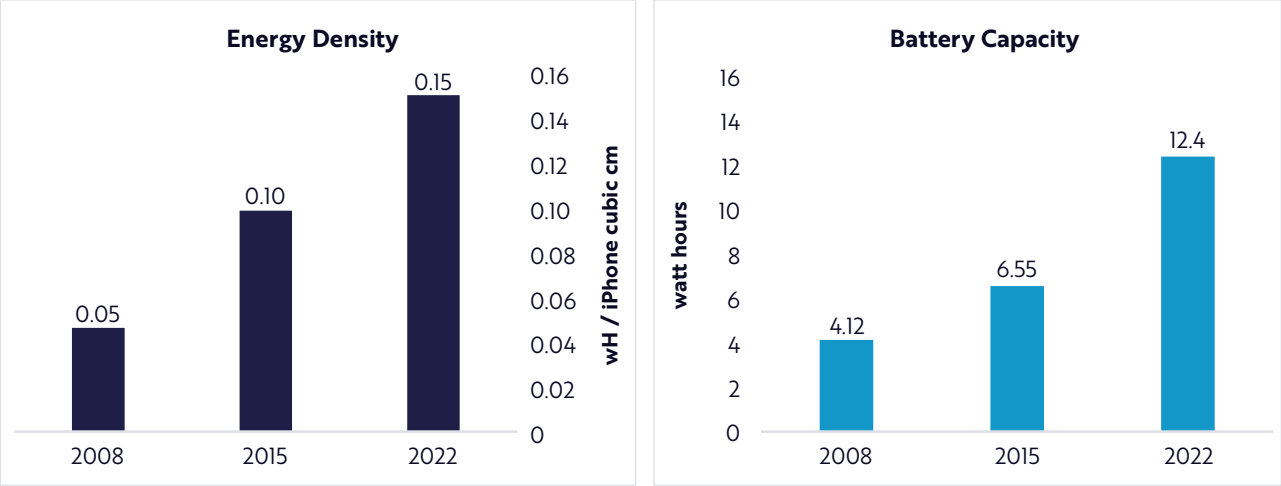
Intelligent devices have evolved because of advances both in power management and computation. We expect the continued advances in battery systems to prove critical for a multifold expansion in the market for intelligent devices, as illustrated below.



Source: ARK Investment Management LLC, 2024. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security or cryptocurrency.

Since its inception when the iPhone's battery lasted roughly one day, advances in energy density have tripled the iPhone's power budget, as shown below. Its sensors now sample the environment more frequently, its camera is more processor-intensive, and it can facilitate power hungry capabilities like streaming video and console-quality video games.

iPhone Battery System Capability Over Time



Source: ARK Investment Management LLC, 2024, based on data from Apple 2023, as of 01/27/23. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security or cryptocurrency. Past performance is not indicative of future results.

Battery system improvements have impacted smaller form-factor devices even more dramatically. The Apple Watch, for example, did not have the power to display time constantly until its fifth generation. "Airpods"—a device that did not exist four or five years ago—now fits in-ear, is not meaningfully power-constrained, and generates tens of billions of dollars in sales.

Improvements in battery capacity and density should prove critical to enabling future intelligent device capabilities. Advanced wearable devices like augmented reality glasses and virtual reality goggles have been severely power-constrained, forcing manufacturers to make concessions like storing the power supply on the user's hip. In our view, the adoption of those devices will be limited until they are comfortable and offer more than a few hours of compelling performance each day. Batteries are the gating factor.

In the history of battery technology, advances in one form factor have unlocked others thanks to increased efficiency and productivity. A boom in laptop demand, for example, pushed the cost of lithium batteries down enough to include them in luxury electric vehicles (EVs); luxury EV demand reduced battery costs enough to enable mass market EV adoption; and mass EV adoption should enable eVTOLS, vertical takeoff and landing craft. Batteries with energy density great enough for aerial mobility, in turn, could power augmented reality glasses.

Convergence enables step-function improvements in technologies, as advances in one technology overcome limitations in others. While the computational requirements of many intelligent devices

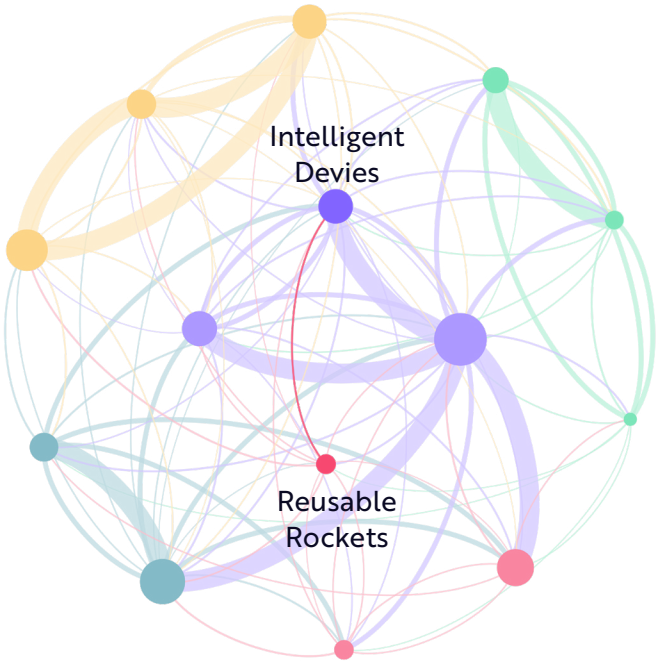
require more energy-dense batteries, advances in neural nets should lower the power intensity of the same devices. The technologies catalyze one another. By penetrating new end markets, one technology can accelerate another's ability to scale.

Convergence Case Study 5: Reusable Rockets as a Catalyst for Intelligent Devices

Convergence score: Mid

The dream of satellite communication is not new.[12] In 1998, Iridium infamously lofted $9 billion[13] in satellites to offer global connectivity but was unable to price the service high enough to reach profitability. It entered bankruptcy in 1999.[14]

Today, thanks to reusable rockets, SpaceX has lofted an active satellite constellation that is 60 times larger than Iridium's original at roughly 20% of the cost,[15] offering more coverage at higher bandwidths, and has attracted 2 million customers—70x more than Iridium around the time of its dissolution. Reusable rockets could create vast new market opportunities for intelligent devices.



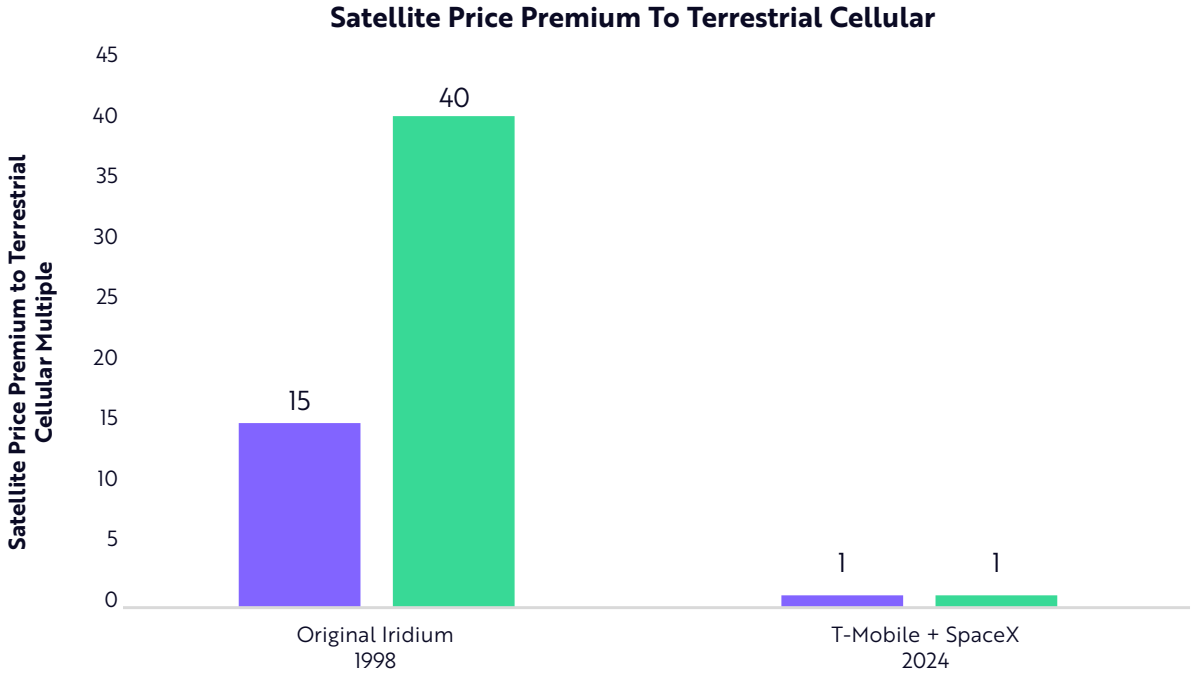
Source: ARK Investment Management LLC, 2024. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security or cryptocurrency.

12 *See Clarke 1945.*
13 *2022 dollars.*
14 *See Mellow 2004.*
15 *As of May 31, 2023, Starlink satellites in orbit exceed 4,000 as compared to 66 in the original Iridium constellation. Starlink sells dishes whereas Iridium sold handsets. Elon Musk has stated that the marginal cost to launch a reused Falcon 9, which can carry roughly 50 Starlink satellites, is $15 million. The satellites themselves have been estimated to cost ~$200,000 per piece. $500,000 in total cost per satellite would suggest $2 billion in costs for a 4,000-satellite constellation. If SpaceX's Starship project succeeds, the cost to launch shou decline precipitously.*

The satellite connectivity enabled by reusable rockets has expanded the number of places in the world where intelligent devices can be connected. Starlink is particularly compelling in rural regions where populations are sparse and traditional fixed-line and cellular solutions are more expensive. Worldwide, there are ~3 billion people who aren't connected to the internet, and Starlink provides connection options for people and places where previously none were available.[16]

In addition to giving populations access to broadband, satellite constellations enabled by reusable rockets should enhance the value and utility of the intelligent devices we already own. SpaceX has announced a partnership with T-Mobile, for example, which will enable smartphones to make satellite calls from anywhere. For its part, T-Mobile will bundle the additional cost into existing wireless plans. T-Mobile has roughly 60x more subscribers than Starlink's 2 million, suggesting that the number of connected satellite users could increase more than 50-fold in the next few years.

Thanks to the new T-Mobile service, we can measure the cost decline associated with satellite connectivity that reusable rockets have enabled, as shown in the chart below. In 1998, the cost of a satellite phone was 15x more than the average cell phone, and the price per minute was 40x higher than terrestrial cellular. Now, with the collaboration between SpaceX and T-Mobile, those price premiums are collapsing to zero.



Source: ARK Investment Management LLC, 2024, based on data from Gregson 1999; Glasner 1999; Hasenstab 1998. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security or cryptocurrency. Past performance is not indicative of future results.

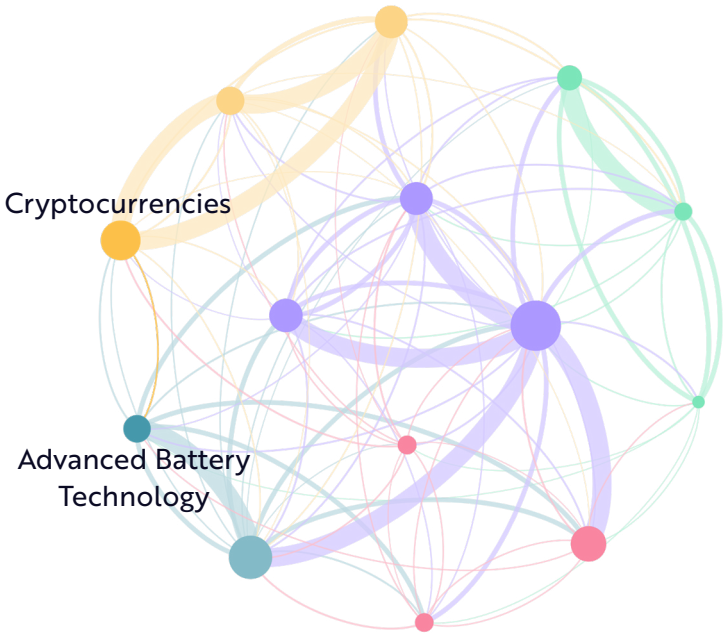
16 *As of 2021, 63% of the population was connected to the internet, according to the International Telecommunication Union (ITU) 2023. G population is 8 billion, according to the United Nations Population Fund 2023.*

Reusable rockets have made intelligent devices like smartphones more capable without much incremental cost to the user. SpaceX's dense, low-earth satellite system is powerful enough to use cellular antennae on existing smartphones. In other words, because of the development of a different part of the global technology stack, smartphones in our pockets today have become more useful—a prime example of convergence in action.

Convergence Case Study 6: Cryptocurrency as a Catalyst for Advanced Battery Systems

Convergence score: mid

Far from the environmental scourge that some pundits claim, bitcoin mining should help balance intermittent energy systems like wind and solar installations efficiently. With time, bitcoin mining should enable the economic installation of large-scale renewable energy and battery systems, which, in a virtuous cycle, should increase the security of the Bitcoin blockchain. We expect cryptocurrency to increase the total addressable market for advanced battery technology significantly, particularly if bitcoin appreciates in value substantially.

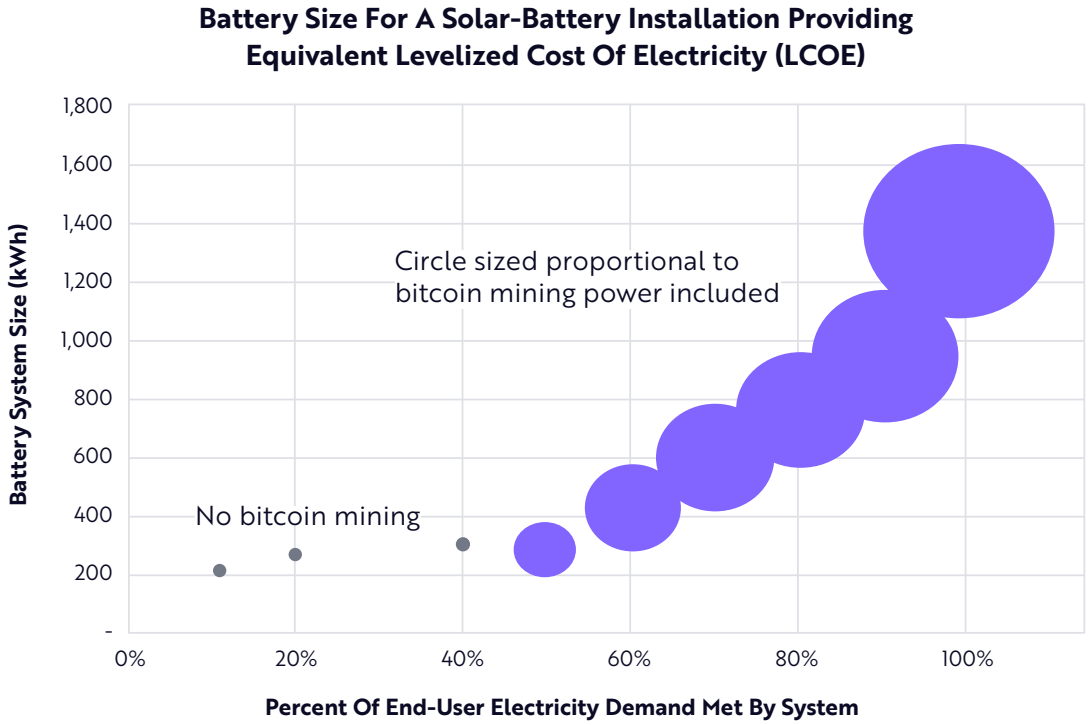


Source: ARK Investment Management LLC, 2024. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security or cryptocurrency.

According to ARK's open-source model on battery systems,[17] a pairing of solar power and energy storage struggles to provide more than 40% of an end user's energy needs before the economics begin to erode. While more solar panels and larger batteries can provide energy throughout the night and during cloudy weeks, at some point the larger systems will generate more energy than

17 *See ARK Invest LLC 2021.*

the grid can handle during sunny summer weeks. Enter bitcoin mining! Bitcoin mining can convert excess energy into bitcoin with little more than an internet connection. Excess energy goes from a waste to a profit center.



Source: ARK Investment Management LLC, 2024, based on data from ARK Investment Management LLC, 2021. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security or cryptocurrency. Past performance is not indicative of future results.

Incorporating a bitcoin miner to use excess energy enables much larger battery and solar systems to operate economically. While a solar-battery system without bitcoin mining can't provide more than 40% of energy needs economically, bitcoin mining allows the system to increase in size without raising the levelized cost of electricity that it generates.[18] ARK's modeling shows that a supersized solar-battery-bitcoin mining system, with a battery 5x larger than the base case, could meet nearly 100% of end user energy demand economically. In other words, adding bitcoin mining allows a solar-battery system to "overbuild" and provide power during cloudy winter weeks at no extra cost to consumers and businesses.

Why is the cryptocurrency-battery systems convergence score not higher if the demand for batteries jumps 5x in this example? The answer is that bitcoin is not valuable enough yet, so its proof-of-work system presently does not consume enough energy to impact battery demand meaningfully. As the bitcoin price increases, however, bitcoin mining could emerge as a globally

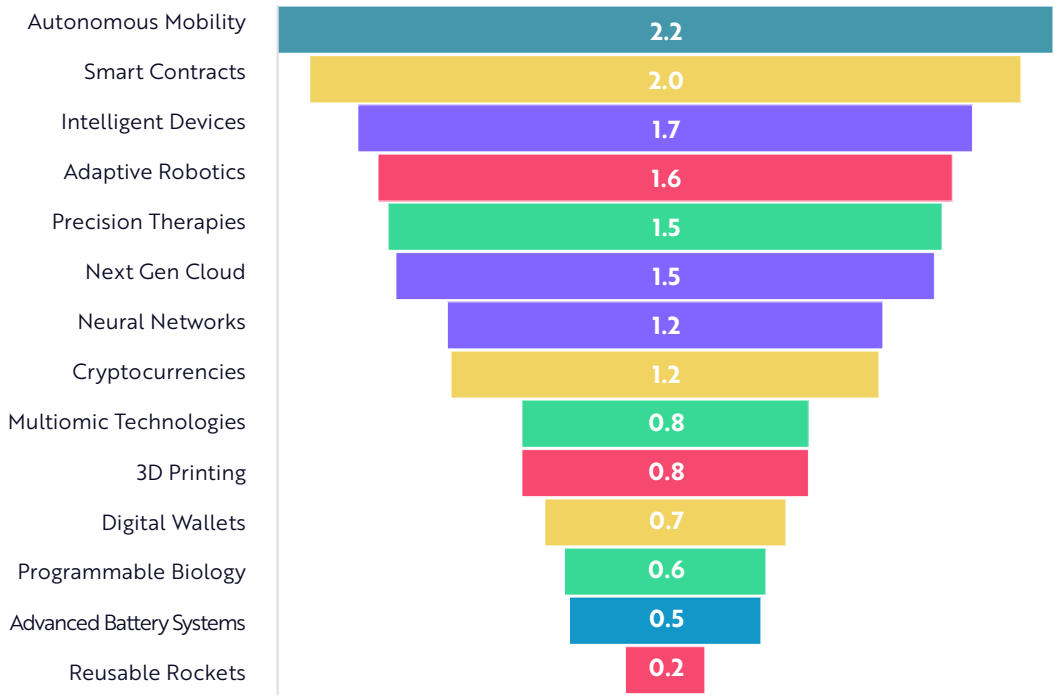
18 *The levelized cost of electricity represents the price that an end consumer would have to pay for the electrical generation system to bre even over the lifetime of the project.*

important new energy tool that would reduce the cost of intermittent wind- and solar-sourced electricity. Should that occur, our cryptocurrency-battery systems convergence score will increase accordingly.

4. Inverting ARK's Convergence Scoring Framework To Gauge Sensitivity To Other Technological Advances

We can invert ARK's convergence scoring framework to determine the degree to which technologies are sensitive to other technological advances. By that measure, autonomous mobility is most sensitive to the rate at which other technologies are changing, as shown below. According to our estimates, if all technological progress in other areas were to cease, the market potential for autonomous mobility systems would be two orders of magnitude smaller than our research otherwise suggests.

Relative Sensitivity To Other Catalysts



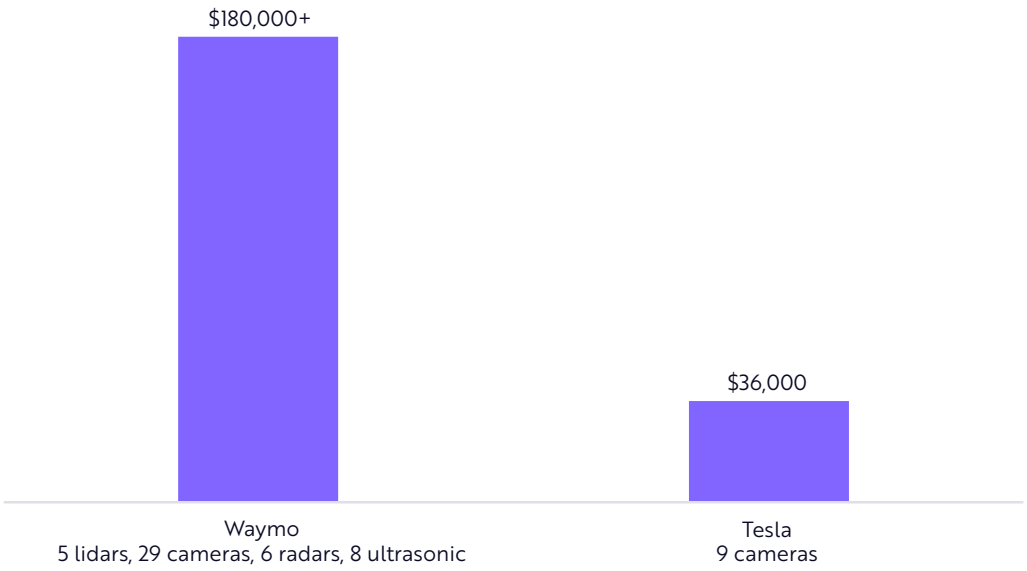
Log of potential increase in addressable market based on other technological advances.

Source: ARK Investment Management LLC, 2024, based on data from ARK Investment Management LLC, 2021. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security or cryptocurrency. Past performance is not indicative of future results.

Autonomous mobility's dependence upon other technologies makes sense. A robotaxi relies on advances in neural networks as well as electric drivetrains, as demonstrated by assets in the field today. Waymo has robotaxis operating commercially, each of which costs as much as $180,000+

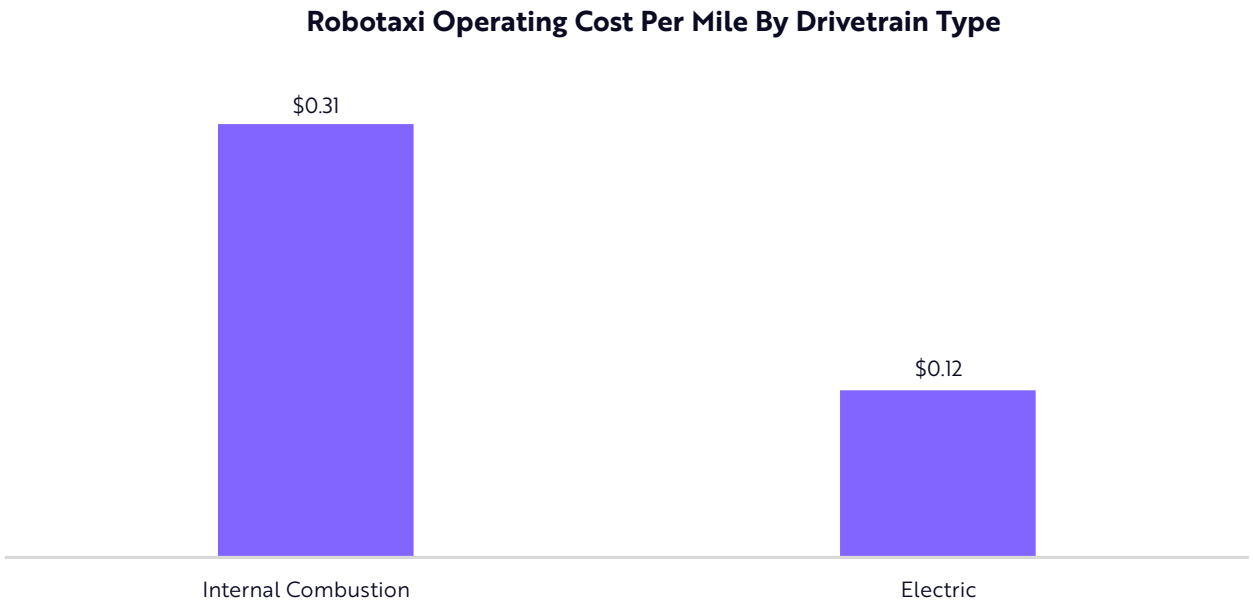
to produce, in part because of their massively complex sensor suites. Tesla suggests that its Model 3 should be able to operate autonomously on a lower-cost, curated sensor set and less powerful on-board computer. If Tesla wins this race, neural network advances will be the reason.

Cost To Manufacture An Autonomous Capable Vehicle



Source: ARK Investment Management LLC, 2024. This ARK analysis is based on a range of underlying sources, which are available upon request. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security or cryptocurrency. Past performance is not indicative of future results. Sources: ARK Investment Management LLC, 2023. Cruise announced a $5 billion debt deal with GM to fund the purchase of "thousands" of vehicles, which would suggest a cost of nearly $500,000 per vehicle. See Cruise2021. In an interview (Moreno 2021), Waymo's former CEO indicated that its vehicles could be produced for a cost of around $180,000. Robotaxi operating cost excludes the amortized cost of the vehicle as well as any costs for a remote operator or service network.

While neural networks can reduce the upfront cost of autonomous vehicles, electric drivetrains can lower vehicle operating costs dramatically. Although saddled with higher upfront costs than the drivetrains in traditional vehicles, electric drivetrains benefit from much lower fuel and maintenance requirements. Moreover, robotaxis could run at 10x the utilization of traditional vehicles, making the lower operating cost model that much more provocative. The shift from a traditional internal combustion drivetrain to electric power reduces marginal costs by more than 60% per mile, as shown below, with robotaxi economics improving by virtue of battery technology advances. Without battery-electric-drivetrains, the ultimate addressable market for robotaxis would be roughly half of what we currently anticipate.



Source: ARK Investment Management LLC, 2024, This ARK analysis is based on a range of external data sources, as of 12/31/23, which may be provided upon request. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security or cryptocurrency. Past performance is not indicative of future results.

Operating at scale, robotaxis should impact other technologies, especially general purpose adaptive robotics. After all, robotaxis and autonomous mobility systems *are* robots operating in constrained domains. Data from robotaxis will likely fuel the neural networks that power humanoid robots. Moreover, the demand for robotaxi motors, actuators, and batteries will reduce the cost of components that feed into general purpose robotics.

SECTION III: 14 Convergent Capabilities In The Year 2030

In this section, we'd like to characterize the convergent technological capabilities that we believe will manifest by 2030. We stress that these scenarios, written in the present tense, are *possible outcomes*—not assured outcomes—and that the future may play out differently.

TECHNOLOGY	2040 POSSIBILITIES	ARK'S 2030 EXPECTATION OF PROGRESS
Cryptocurrencies	Cryptocurrencies have displaced most permission-based, centrally controlled monetary systems, enabling financial ecosystems to reformulate around a digital asset that can eliminate counterparty risk while continuing to facilitate transaction flows. The reformulation began at the edges of the traditional financial system in geographies with broken money systems and in markets otherwise mis-served by traditional financial intermediaries. In developed markets, cryptocurrencies initially served as a store of value, providing little direct utility. Over time, the efficiencies of a truly neutral digital currency, primarily bitcoin, have prevailed over other financial architectures.	Global money supply has grown in tandem with GDP, and cryptocurrencies now account for ~10% of the total. Little of that value accrual is attributable to the direct displacement of money though there are instances in emerging markets. Much of the appreciation is a function of low single-digit percent allocations by institutional and high net worth individuals as well as corporate and nation-state treasuries. Cryptocurrencies continue to displace gold as a flight-to-safety asset, taking 40% share of the market. Utility use cases such as remittances and global settlements account for ~10% and~ 5% of volumes, respectively
Smart Contracts	Most contracts have migrated to open-source protocols that enable and verify digital scarcity and proof of ownership. Risk-sharing arrangements are more transparent, assets of all sorts are securitized, bought, and sold more easily, and counterparty risks have diminished substantially. The importance of traditional financial intermediaries has dwindled, even as more human activity becomes commercialized. Decentralized protocols, enabled by balance-sheet-light digital wallet platforms, facilitate most traditional financial functions. Consumer internet services rely on business models enabled by digital asset ownership. Every corporate entity and every consumer has adapted as centralized corporate structures themselves are called into question.	Global financial assets as percent of GDP have continued to increase, with less than 5% secured by smart contracting platforms—a dynamic consistent with the adoption curve of dialup internet. At 1%, the gross take from tokenized assets on decentralized protocols is less than a third of the fees that traditional financial institutions extract. Application protocols, which pay a larger share of fees to incentivize network participants, account for 75% of gross decentralized protocol revenues. The blended net take rate between application layer protocols and Level 1 protocols is roughly 60bps.
Digital Wallets	Digital wallets enable nearly every person with a connected device to transmit and receive money instantly, fundamentally transforming the through-flow of commercial and financial experiences. Digital wallets that facilitate wholesale pricing of financial services for individual users have disrupted retail banking relationships, fundamentally transforming consumer relationships with financial service providers. In addition to their financial functions, digital wallets are distribution platforms for a variety of digital services—from ride-hailing to e-commerce—and are secure repositories for digital health and other sensitive data. Traditional financial service institutions and their associated payment processing value chains have given way largely to internet-enabled digital wallets for most economic activity.	Roughly 90% of smartphone users rely on digital wallets to some degree. The majority uses digital wallets as the front-end for more than half of meaningful financial functions. Digital wallet platform providers continue to rely on traditional ecosystems to facilitate financial activities like lending but can extract lead generation fees of 5-20% for delivering customers to those institutions. They also can capture 3-10% commerce facilitation fees for e-commerce activity directed through their platforms.

TECHNOLOGY	2040 POSSIBILITIES	ARK'S 2030 EXPECTATION OF PROGRESS
Precision Therapies	Technology enables the manipulation of molecular biological systems, catalyzing a new generation of more efficacious and durable precision therapies. CRISPR-based gene-editing enables the manipulation of DNA directly with increasing specificity. RNA-acting therapeutic techniques restrict the area of DNA that can be transcribed into proteins. AI-advances enable the targeting of specific proteins that cause underlying disorders. These breakthroughs have shortened development timelines for and increased the efficacy of curative therapies that command higher prices than traditional therapies. Researchers are aiming to cure most rare diseases. Traditional health service spending declines, ceding economic terrain to molecular cures.	Precision therapies make up 25% of newly released drugs. By improving the quality of life, lowering ancillary medical costs, and often effectively curing diseases, they command average price premiums of 7x relative to traditional drugs. Combined with expected improvements in R&D efficiencies, these drugs add 15% or ~$300 billion to drug revenues in 2030.
Multiomic Technologies	Catalyzed by the precipitous fall in sequencing costs, researchers and clinicians routinely collect patients' epigenomic, transcriptomic, and proteomic data. With increasingly comprehensive digital health readouts from intelligent devices and emerging AI tools, they align this panoply of multiomic data to understand, predict, and treat disease. As a result, cancer care has transformed completely: multiomic technologies detect cancer at early stages, target treatment more precisely, and provide recurrence monitoring. Regular blood-based pan-cancer tests are a standard of care for patients in middle age. Multiomic technology has increased biotech R&D efficiency, as clinical trials target patient populations and measure outcomes more precisely and easily. Combined with AI, multiomic technology has transformed the relationship between patients and health systems. Digital health providers, diagnostic tool companies, and molecular testing companies are leading the charge. Legacy drug franchises and health service systems have lost their prominence. Wasteful healthcare spending declines as healthy lives extend.	At full penetration, R&D efficiency associated with drug development could double, thanks to AI-enhanced multiomic technology. By 2030, nearly all new drug development programs incorporate multiomics into preclinical R&D, and ~50% incorporate AI into clinical programs. Realized returns on R&D have improved by 10% with line-of-sight to a near doubling of R&D returns by 2035. Early detection multi-cancer blood tests have become standard of care as they have cut cancer mortality by 25% for some age cohorts. In developed markets, 30% of patients benefit from the new diagnostics regime.
Programmable Biology	AI tools, improved genomic synthesis techniques, and scalable biological manufacturing techniques enable novel, lower cost biological constructs with predictable performance, powering a renaissance in agriculture and materials science. Programmable biology enables breakthroughs in materials science and bio-based fuels that increase food production and reduce environmental externalities. Molecular biological primitives offer a substrate for new robust computation architectures.	Still restricted to early stage and development projects, gene synthesis generates $10 billion in annual revenue. Programmable biology platforms capture 10% of precision therapy revenue. Those platforms generate another $30 billion in revenue with gross margins at ~70%, EBITDA margins in the 35% range, and free cash flow margins at ~20%.

TECHNOLOGY	2040 POSSIBILITIES	ARK'S 2030 EXPECTATION OF PROGRESS
Autonomous Mobility	Robots move people and parcels from place to place and have changed the economics of physical movement entirely. The cost of taxi, delivery, and observation have fallen by an order of magnitude. Traveling by robotaxi is the norm and owning a personal vehicle the exception. Frictionless drone and robot delivery has catalyzed the velocity of ecommerce. The data generated by autonomous mobility systems provide pervasive, real-time insights into the state of the world. Consumers and businesses that harness autonomous mobility platforms are benefitting, while prior incumbents in the automotive, logistics, retail, and insurance sectors have been upended.	Autonomous robotaxis have transformed global transport, as point-to-point transportation is available in nearly every country at an average price of ~$.50 per mile. Given the compelling price-point and utility, robotaxis have traveled 13 trillion vehicle miles and are gaining traction. Autonomous robotaxi platforms charge platform fees or take-rates of 50%+, generate ~50% operating margins, and give asset owner-operators the opportunity to generate reasonable rates of return on capital. The number of autonomous vehicles facilitating this travel is ~100 million, and most of the incremental vehicle production is autonomouscapable.
Advanced Battery Systems	Declining battery costs have ignited a Cambrian explosion in mobility form factors, pushing electrical supply out to end-nodes on networks. Electric vehicles dominate transport as internal combustion dies. Micro-mobility and aerial systems that include flying taxis enable innovative business models that transform urban landscapes. All these innovations drive fundamental demand for electrical energy at the expense of liquid fuel. They also provide electrical energy more efficiently, reducing the vulnerability of grids, operational expenses, and the capital intensity of transmission and distribution. Oil demand is in decline, and traditional automotive manufacturers and suppliers have been displaced by a smaller number of vertically integrated technology providers.	As ridership shifts to electric autonomous platforms, the number of autonomous capable EVs sold annually is ~74 million, accounting for most of the automotive market. At an average selling price of ~$20,000, EV manufacturers generate $1.4 trillion in annual revenue, ~20% gross margins, and ~10% EBIT margins. With manufacturing consolidation, margins increase. Batteries account for ~20% of the value of EVs. Much like that of EVs, battery manufacturing is capital-intensive and low-margin. Supplying the EV OEMs, battery manufacturers generate revenue of $300 billion per year. Stationary energy storage requires a volume of batteries roughly equivalent to that consumed by EVs, generating another $300 billion in revenue.

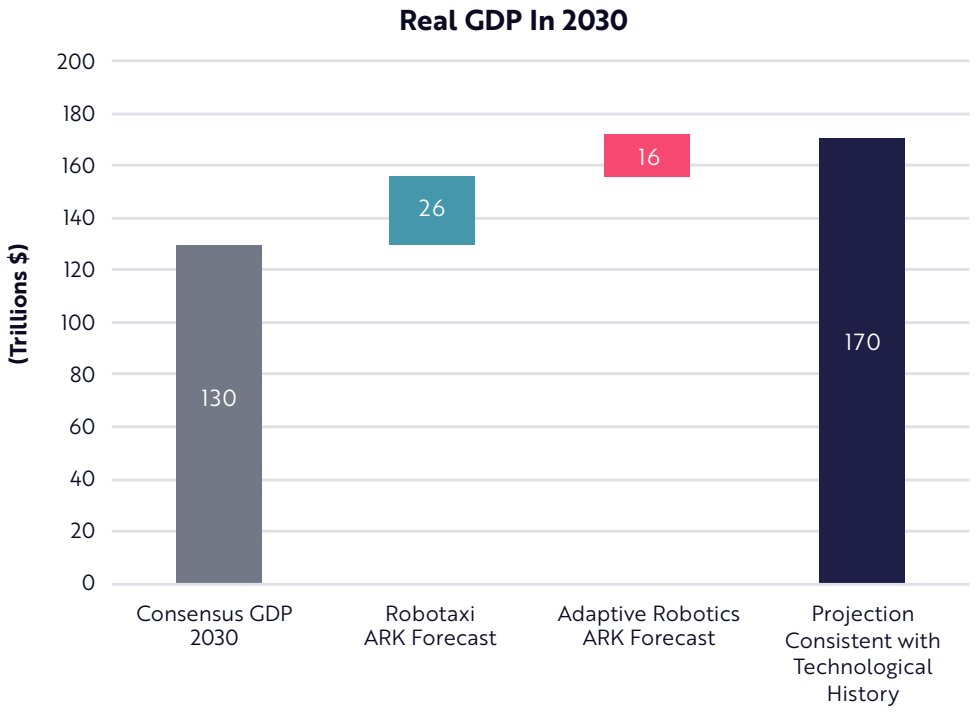
TECHNOLOGY	2040 POSSIBILITIES	ARK'S 2030 EXPECTATION OF PROGRESS
Neural Networks	Fed by massive amounts of data, computational systems and software are solving previously unsolvable problems, automating knowledge work, and accelerating the integration of technology into all economic processes. As costs have plummeted, custom software is improving with every AI model enhancement and connecting the world. Learning systems are blazingly fast, their impact as momentous as the introduction of the microprocessor, transforming every sector and region.	The cost of training AI models has fallen more than 40,000-fold which, when combined with aggressive investments in AI hardware, has catapulted aggregate AI capability roughly 600,000-fold since 2023. Adopted by 50% of knowledge workers, AI software systems have improved their productivity by 9x on average. Consistent with other software products, enterprises pay 10% of the productivity increase to access the software.
Next Gen Cloud	Cloud tools train the AI models that dominate software stacks and the software connections that stitch together the AI-run world. The infrastructure-as-a-service providers, chip manufacturers, and toolmanufacturers that facilitate the training of neural networks have enjoyed a multi-decade demand cycle. Software development has been democratized, and the companies providing API hooks that stitch together interoperable software layers experience unprecedented demand	AI hardware spend of $1.3 trillion supports $13 trillion in AI software sales and accommodates traditional software gross margins of 75%. Three types of customers support the demand for AI hardware--infrastructure-as-a-service providers, software companies, and AI foundation model providers—which should generate 20% cashflow margins, consistent with those of chip manufacturers.
Intelligent Devices	AI powers a new class of intelligent devices in the home and on the go. Fixed internet-and AI-powered infrastructure exists in homes and other social environments, transforming distribution for all media providers. Endusers interface with the world in completely new ways, and data on their consumption preferences spawn new business models and services. Commerce and wagering permeate entertainment experiences, enabling and catalyzing new advertising formats and content monetization. The show is the store. Linear TV is obsolete, as digital curation and direct consumer preference drive visual content. Linear content is ceding ground to interactive experiences, sometimes subtly. AI-mediated glasses and headsets thread through the fabric of everyday life.	Consumer spending on intelligent device hardware continues its uptrend to ~$60 per internet user per year. Time spent connected grows dramatically to half of waking leisure hours, or 20 trillion globally. Digital experiences continue to monetize at a discount to in-person experiences and yield $0.25 per hour spent online in revenue to platform providers. Between device spend and digital entertainment experiences, $5.4 trillion in revenue accrues to intelligent devices, entertainment, and social platforms. Advertising and commerce comprise 80% of that revenue.

TECHNOLOGY	2040 POSSIBILITIES	ARK'S 2030 EXPECTATION OF PROGRESS
Reusable Rockets	Reusable rockets are inexpensive and have spawned new business models. Low-earth orbit constellations connect every smartphone user on earth to a censor-resistant data feed. Hypersonic point-to-point travel is becoming a reality, disrupting long-haul flight, transforming military asset delivery, and shrinking global supply chains. Extra-planetary human exploration has begun ramping.	Led by SpaceX's Starship launch volumes, a 40,000 strong satellite network is in orbit, facilitating direct-to-satellite communications for nearly all smartphones and delivering broadband-type speeds to ships, RVs, airplanes, and rural residents in developed and developing countries. Given the relative ease with which customers can be on-boarded—a power outlet, an antenna, and a clear path to the sky—most customers are engaged in an addressable market totaling $130 billion annually.
Adaptive Robotics	Adaptive robots powered by artificial intelligence are transforming the economy. The cost of humanoid robots that are backward-compatible with existing infrastructure has dropped below that of human manufacturing labor for many applications. Previously intractable household tasks are submitting to automation at price points that create compelling endmarkets. Fleets of robots grow more performant with every AI software upgrade. A virtuous circle of fleet data generation and AI model training drives performance forward. Manufacturing productivity growth accelerates as a wider array of physical goods submit to technologically-driven cost declines. Robots continue to penetrate the service sector as well. The economy has entered a period of undeniable and unprecedented explosive growth.	Adaptive robots have penetrated manufacturing processes enough to increase productivity by 15%, and annual unit sales of humanoid robots have grown to 10% of the number of humans in the manufacturing workforce. Less expensive robots in human form-factors have begun to populate households, particularly in developed countries. While still limited in capability, these robots address a third of household chores, their sticker prices justified by the time that household members save. Robot manufacturers enjoy margins at the higher end of capital equipment suppliers, thanks to software.
3D Printing	3D printing has removed design barriers and reduced cost, weight, and time to production, dramatically transforming traditional manufacturing methods. Healthcare tools created with 3D printing are personalized and custom-made, resulting in better experiences for both patients and doctors. Lighter 3D-printed aerospace parts reduce global emissions and give flight to new aircraft both for earth and outer space. Replacement parts across industries are printed on demand at a fraction of previous costs, ultimately short-circuiting supply-chain shortfalls. 3D printing enables artificial intelligence to design parts once impossible to manufacture.	3D printing continues to dominate the prototyping market and has penetrated substantial parts of the intermediate tooling market, enabling low-cost design iterations across injection molding and metal casting applications. Most important to industry growth, 3D printing has begun to see meaningful uptake into end-use applications across aerospace and automotive, markets that collectively sell more than $4 trillion in equipment per year. Across all industries, nearly $900 billion in end-use parts could adopt 3D printing, though that penetration remains in the teens.

SECTION IV: CONCLUSION

ARK's technological forecasts point toward a discontinuous inflection in economic growth consistent with techno-economic history. When technologies converge—when S-curves in one technology feed S-curves in another[19]—innovation can catapult the global economy into a higher real growth regime. Although the historical economic growth trajectories presented in section I suggest that such a discontinuous change is possible, historical data alone are insufficient to specify the timing of the structural change. Our technological forecasts suggest that the time is now—that a new era of accelerating macroeconomic growth will begin this decade. Indeed, our work shows that just two of the technologies more likely to be well-captured by macroeconomic statistics should be sufficient to establish a new macroeconomic growth regime.

According to our research, robotaxis and adaptive robots alone will push global GDP toward $170 trillion in 2030, as shown below. We focus on robotaxis and adaptive robots not only because they are likely to generate that growth, but also because the productivity boost from these technologies is more likely to be well-measured by traditional economic statistics.



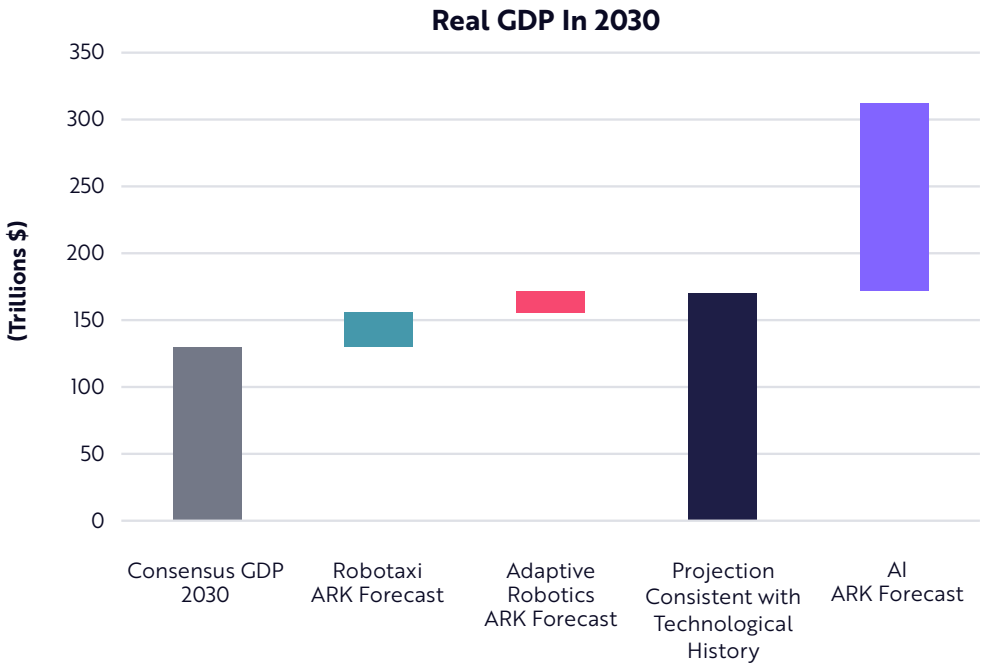
Source: ARK Investment Management LLC, 2024. This ARK analysis is based on a range of underlying sources, including Nalley et al. 2021, which are available upon request. Macroeconomic forecasts are consistent with the information presented in Convergent Capabilities Tables on pp. 33-37. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security or cryptocurrency. Past performance is not indicative of future results.

19 *The S-curve illustrates the adoption and growth pattern of new technologies, characterized by an initial slow growth, followed by rapid adoption, and culminating in a tapering off as the technology saturates the market.*

Given the inexpensive convenience of robotaxis, unpaid labor should transform into a paid service; the amateur work of driving manually—not captured in economic statistics—is likely to convert into the government-measured production of robotaxi networks. Adaptive robotics that increase manufacturing productivity also should cause a well-measured boost in output. Similarly, household robots that do manual chores likely will transform non-market housework into economic production through robot sales and operating costs.

While all the technologies upon which we have built our research and investments are likely to increase productivity significantly, it is less clear to what degree they will feed into traditional measures of GDP. A multiomics breakthrough that extends human life for the same cost as existing standards of care, for example, is likely to be measured as a positive macroeconomic advance *indirectly*—and, even then, only if the longer-lived person remains in the workforce.

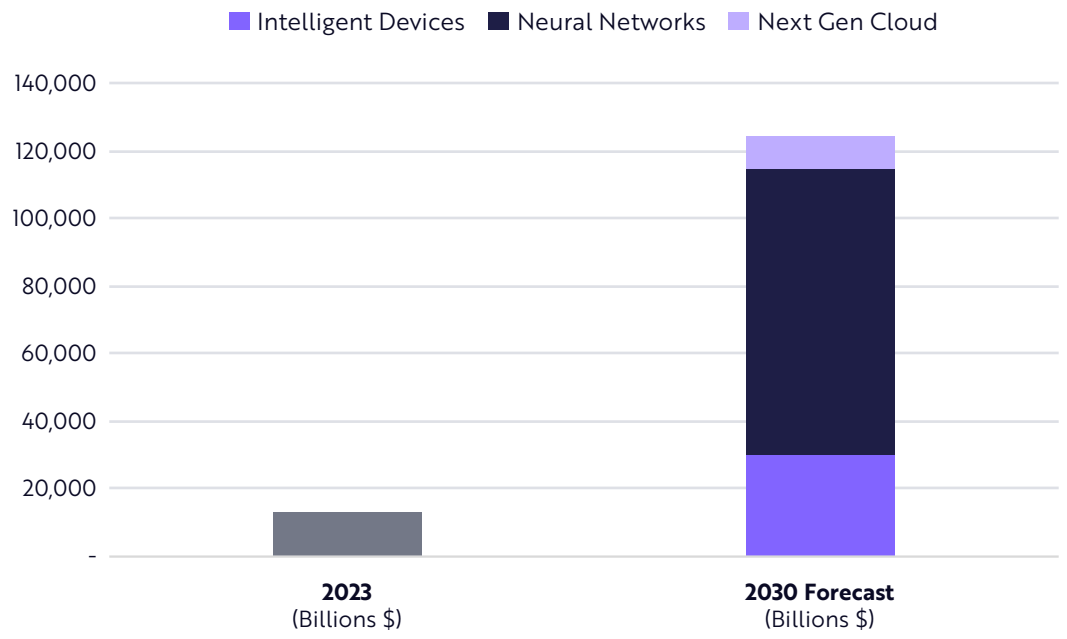
AI productivity also is unlikely to be captured adequately by traditional GDP accounting. AI software is already improving[20] the productivity of knowledge workers, a job category that should command ~$30 trillion in wages by 2030.[21] Force-multiplying the world's knowledge worker labor force with AI should produce profoundly better software, analysis, and consumer experiences. The total value of knowledge work that is conducted with the help of AI software could reach ~$130 trillion.[22] While traditional production statistics—many born in the industrial age—are unlikely to capture that boost right away, the impact on consumer welfare should be profound.



Source: ARK Investment Management LLC, 2024. This ARK analysis is based on a range of underlying sources, including Nalley et al. 2021, which are available upon request. ARK Invest macroeconomic forecasts are consistent with the information presented in Convergent Capabilities Tables on pp. 33-37. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security or cryptocurrency. Past performance is not indicative of future results.

20 *Dell'Acqua 2023; Kalliamvakou 2022.*
21 *Excluding China.*
22 *This number is representative of the additional wage bill that would be required at 2023 productivity levels to produce the volume of knowledge-work output that we anticipate by 2030.*

Artificial intelligence systems promise to deliver profound productivity advances—roughly ~$130 trillion, by our estimates—for which businesses should be willing to pay. As detailed in section III, intelligent devices, neural networks, and next gen cloud technology businesses collectively could command $120 trillion in market value. This forecast would be consistent with businesses paying out only 10% of the productivity boost that they yield from AI, and capital markets valuing those disruptive technology businesses somewhere between 8 and 9 times revenue—a credible outcome given the expected margin-structure and defensibility of those revenue streams.



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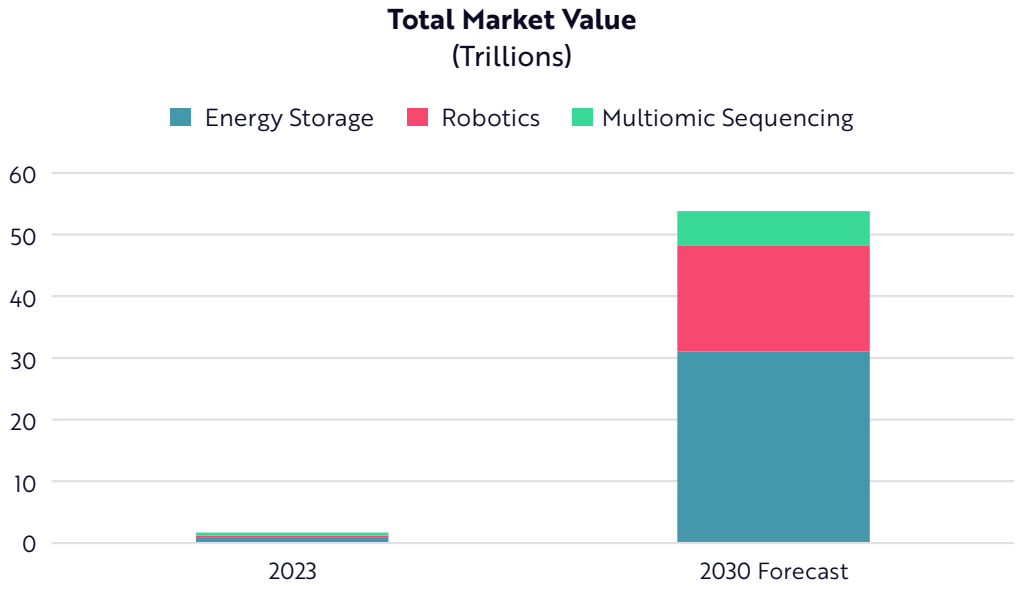
The robotics, energy storage, and multiomics sequencing innovation platforms also should accrue meaningful market value, commensurate with their contribution to economic production. As shown previously, robotaxis and adaptive robots collectively should increase economic production by $40 trillion by 2030. Businesses associated with these technologies—including advanced batteries, reusable rockets, and 3d printing—should accrue more than $40 trillion in market value by 2030. Adding multiomics technologies—including precision medicine and programmable biology—takes the total to $50 trillion in market value by 2030, up more than 50% at an annual rate from roughly $2 trillion today, as shown below.



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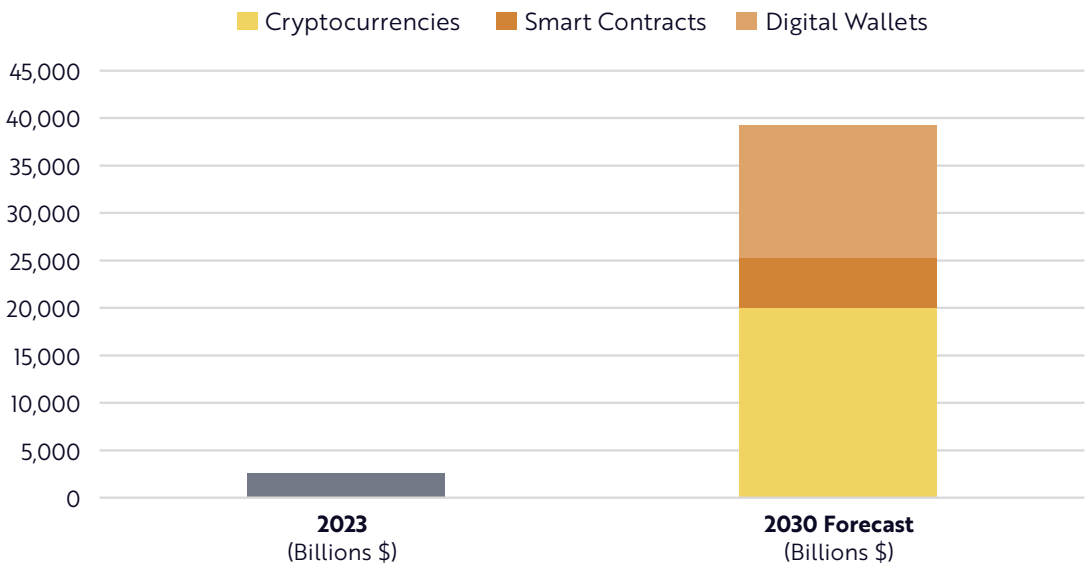
Measured across smart contracts, digital wallets, and cryptocurrencies, we expect market value associated with the Public Blockchain innovation platform to reach ~$40 trillion by 2030. Cryptocurrencies—and, to a lesser extent, smart contract protocols—are likely to compete with fiat currencies. On that basis, the $25 trillion estimate of market value implies a ~10% share gain of cryptoassets against a money supply, which should grow in tandem with the innovation-fueled economy to reach ~$240 trillion by 2030. Catalyzed by and catalyzing the penetration of public blockchains, digital wallets are likely to displace traditional banking relationships and serve increasingly as the front-end to consumer's financial lives, adding ~$14 trillion in business value, as shown below.



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According to our research, the five innovation platforms together will generate more than $200 trillion in market value by 2030. If the portion of the equity market not exposed to innovation were to deliver low single digit percentage returns—though disruptive technology could subject legacy businesses to harsher outcomes—the five converging innovation platforms could account for more than 60% of global equity market values by the end of this decade.

The techno-economic discontinuities that we believe are underway are creating the potential for unprecedented economic growth. When two waves align, one stacks atop the other, creating "constructive interference." Under the right conditions, converging waves entrain, and resonance aligns multiple waves, enhancing constructive interference; waves stack upon waves, building to unprecedented heights. In our view, technological convergence is creating the same kind of alignment—effectively, the constructive interference of S-curves. The technological acceleration is palpable. The acceleration in artificial intelligence is pulling forward every disruptive technology. A more transformative future is coming faster than even we had anticipated. We are entering a new techno-economic age.

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Brett joined ARK in February 2014 and has worked alongside Cathie for almost 15 years since their time at AllianceBernstein. As Chief Futurist, Brett drives ARK's long-term forecasts across convergent technologies, economies, and asset classes, helping ARK dimension the impact of disruptive innovation as it transforms public equities, private equities, cryptoassets, fixed income, and the global economy. Brett also serves on the ARK Venture Investment Committee. Brett joined ARK as Director of Research, guiding and managing the proprietary research of ARK's investment team.

Prior to ARK, Brett served as a Vice President and Senior Analyst on the Research on Strategic Change team at AllianceBernstein. In that role, Brett conducted thematic research, served on the thematic portfolio's strategy committee under Cathie Wood's stewardship, and advised portfolio managers across asset classes. His research topics included Global Energy in the Face of Carbon Dioxide Regulation; Social Media and the Rise of Facebook; the Reformation of the Financial Services Landscape; and the Emergence of Electric Vehicles.

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