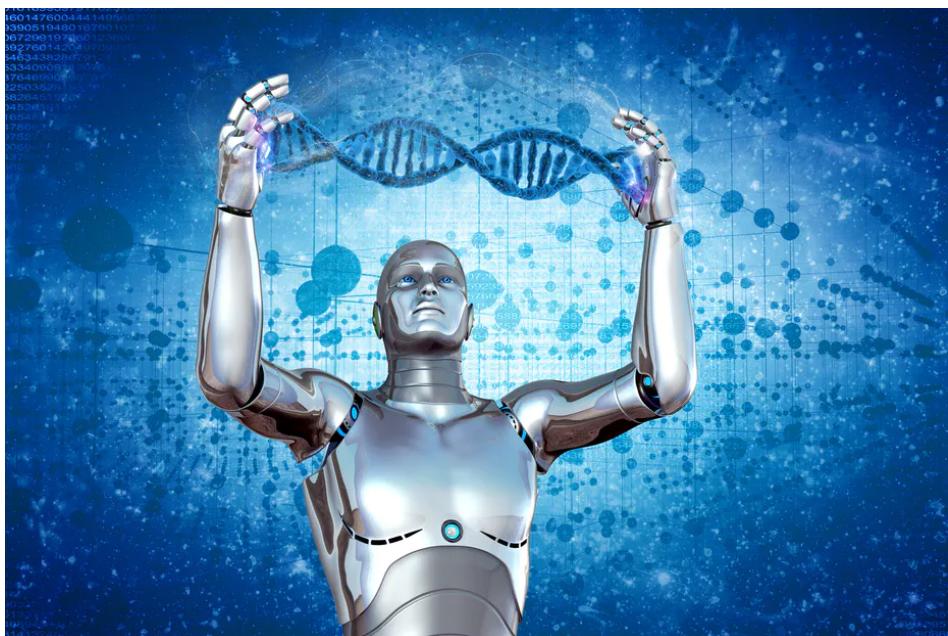


Responsible development of new technologies critical in complex, connected world

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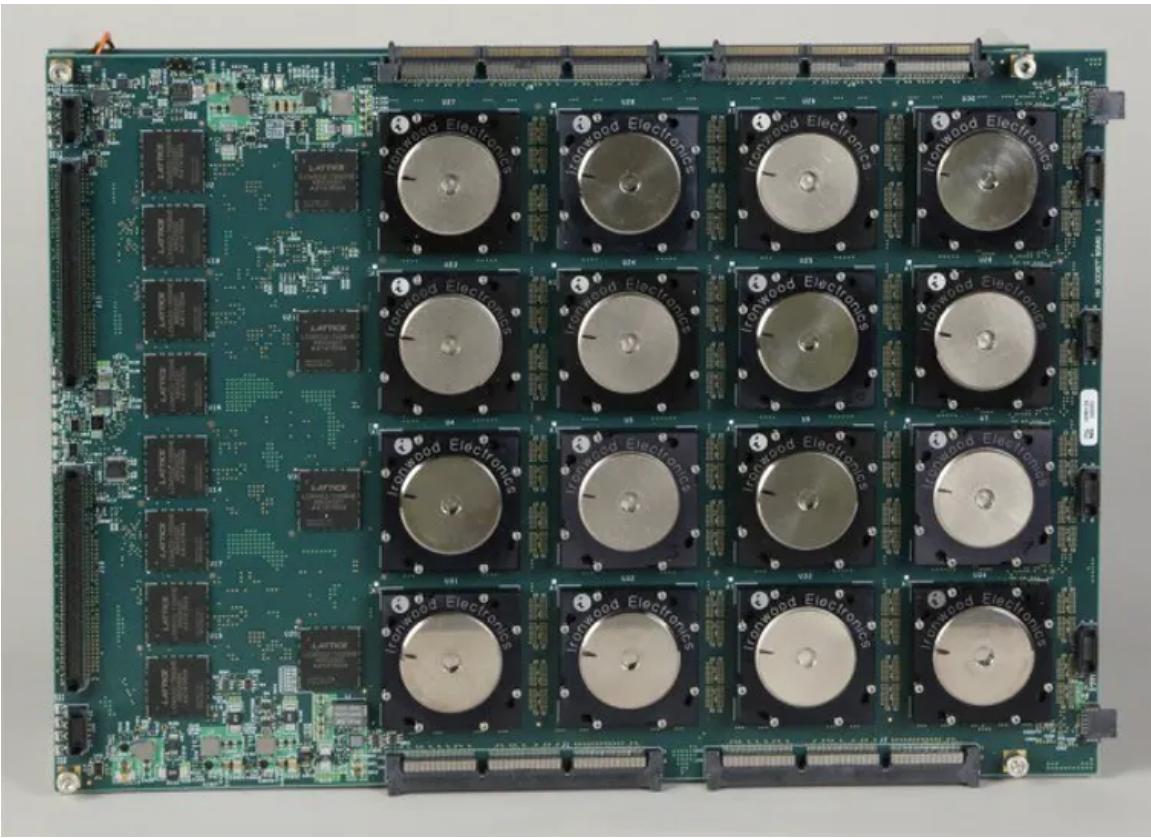
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With emerging technology comes great responsibility. Robot image via www.shutterstock.com.

On July 31, 2012, a massive blackout swept across northeast India. At 1 pm local time, a power line in the state of Madhya Pradesh became overloaded and tripped out. As the supply grid struggled to pick up the slack, other lines went down. By 1:03, a cascading series of failures had pushed the electricity supply grid into a state of chaos, resulting in the largest blackout in human history. More than an estimated 600 million people lost power temporarily as a result of the collapse.

This blackout is a stark reminder of how vulnerable we all are to chaotic collapse around the many complex technological systems we rely on. Yet we continue to develop powerful new technologies at a rapid rate, with little thought as to how their very complexity and interconnectedness may cause them to unravel in the future.



Neuromorphic chip with a maximum load-equivalent to 400 billion synaptic operations per second per watt. Day Donaldson, CC BY

The sheer audacity of our technological prowess is reflected in this year's list of Top Ten Emerging Technologies from the World Economic Forum (WEF) – now in its fourth year. The list spans advances in genetic engineering and the use of rapid DNA sequencing and digitization for personalized health care, to artificial intelligence, neuromorphic computer chips that mimic the human brain, and advanced robotics.

The list, which is intended to raise awareness on the potential benefits and possible pitfalls around leading emerging technological trends, is an impressive testament to how rapidly our ability to control and manipulate the world around us is changing. Yet it also spotlights the inherent dangers of runaway innovation and the need for the responsible development of emerging technologies.



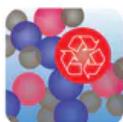
1 FUEL CELL VEHICLES

Zero-emission cars that run on hydrogen



2 NEXT GENERATION ROBOTICS

Rolling away from the production line



3 RECYCLABLE THERMOSET PLASTICS

A new kind of plastic to cut landfill waste



4 PRECISE GENETIC ENGINEERING TECHNIQUES

A breakthrough offers better crops with less controversy



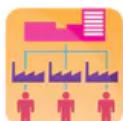
5 ADDITIVE MANUFACTURING

The future of making things, from printable organs to intelligent clothes



6 EMERGENT ARTIFICIAL INTELLIGENCE

What happens when a computer can learn on the job?



7 DISTRIBUTED MANUFACTURING

The factory of the future is online – and on your doorstep



8 'SENSE AND AVOID' DRONES

Flying robots to check power lines or deliver emergency aid



9 NEUROMORPHIC TECHNOLOGY

Computer chips that mimic the human brain



10 DIGITAL GENOME

Healthcare for an age when your genetic code is on a USB stick

World Economic Forum Top Ten Technologies 2015. World Economic Forum/Andrew Maynard, CC BY-NC-SA

Innovation isn't automatically for the good

Take artificial intelligence (AI), for instance - one of the WEF Top Ten technologies. Both Elon Musk and Stephen Hawking have warned against the risks of out-of-control AI. Earlier this year, they signed an open letter highlighting the opportunities and challenges around developing robust and beneficial AI. The letter acknowledges that, without foresight and due consideration, AI's promise of substantially augmenting human intelligence as we seek to eradicate disease, make better use of available resources and improve quality of life, could be undermined by unanticipated drawbacks. Imagine, for instance, the dangers of maliciously programmed autonomous weapons, or intelligent machines that don't understand or respect human values.

Other technologies in the WEF Top Ten present similar challenges. Drones raise concerns around security and privacy. The digital genome brings us closer to Gattaca-like discrimination practices based on our DNA. Precise genetic engineering techniques enable the ethically complex re-design and re-invention of living organisms. Additive manufacturing methods such as 3-D printing raise new challenges in how novel materials and processes are used safely.

These technologies are not inherently safe and secure. Yet they're nevertheless critically important because of their potential benefits.



Even basics like clean drinking water aren't guaranteed for all people. Shawn, CC BY-NC-SA

We need tech to address world problems

Despite possible downsides, society needs technology innovation. We live in a world where one billion people are still without basic sanitation. Over six million children die each year before reaching the age of five. Over 14% of the world's people each live on less than US\$1.25 a day. More than 2.5 billion people are at risk from infectious diseases like dengue and malaria. Ensuring sufficient water, food and energy to sustain acceptable living standards will become increasingly challenging in the coming years.

Technology innovation alone will not solve these and other challenges. But without it, many will not be solved at all.

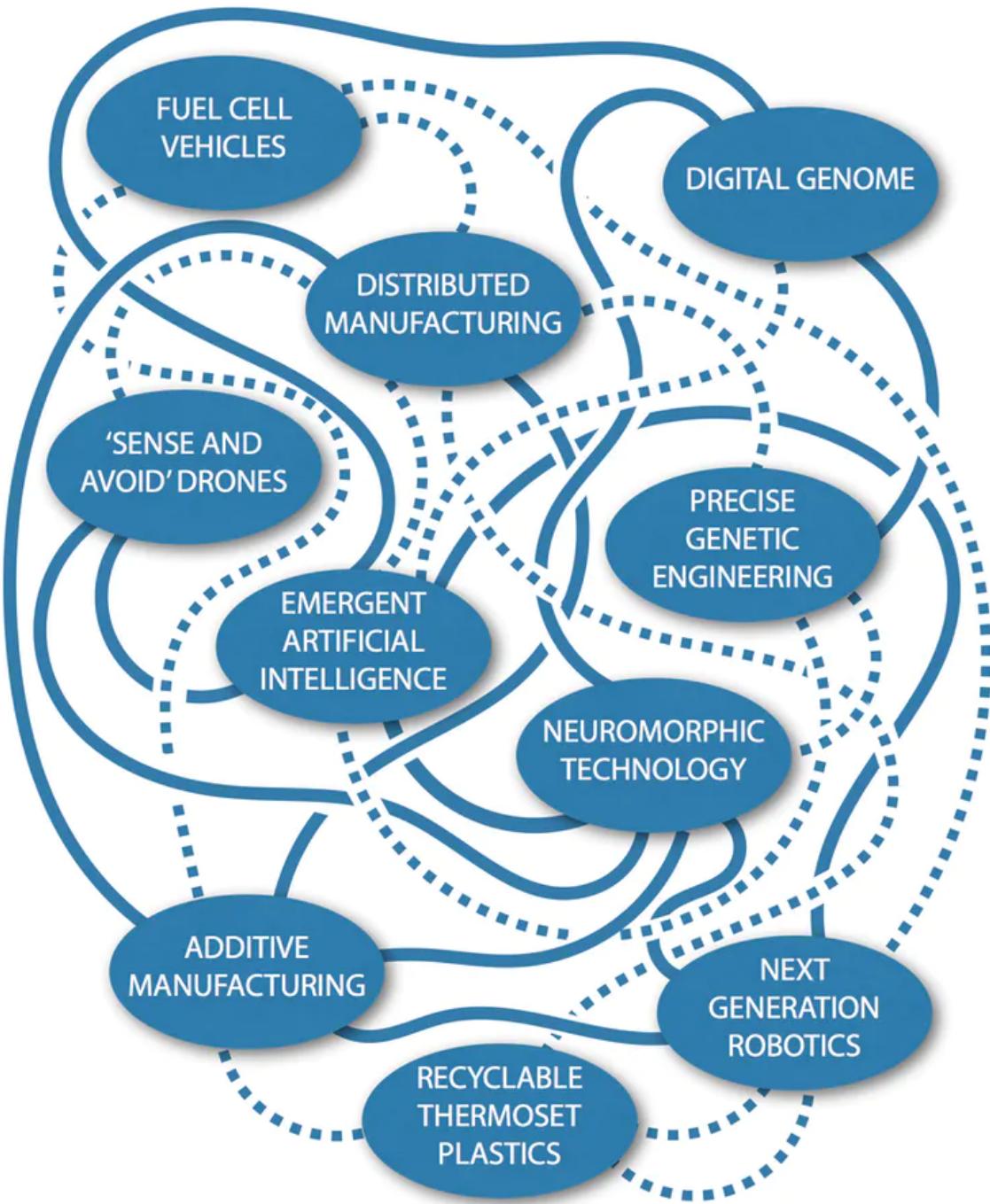
So we can't afford to slam the breaks on emerging technologies. Each of the WEF Top Ten technologies holds the promise of advances that will change lives for the better. From novel recyclable plastics, to advanced manufacturing processes, to the possibility of personally tailored health programs, these technologies represent the tip of an innovation iceberg that could help eradicate disease, alleviate poverty and inequality, and help address some of the most pressing challenges of our time.

Yet good intentions alone will not ensure we see the benefits of these technological breakthroughs.

Tech doesn't emerge into a vacuum

In January of this year, the Stockholm Resilience Center released research indicating that we're rapidly pushing our planet toward a harmful tipping point. The Center previously identified nine planetary boundaries within which humanity can continue to develop and thrive. They warned that crossing these boundaries "could generate abrupt or irreversible environmental changes." According to researchers, four of these boundaries (including climate change and biosphere integrity) have now been crossed as a result of human activity.

Emerging technologies are amplifying this coupling between our actions and our environment. Whether through new approaches to reducing environmental impact (the development of fuel-cell technologies or innovative recyclable materials, for instance) or technologies that have the potential to radically alter human-environment interactions (for instance, applications of AI and distributed manufacturing), there is an intimate and complex dynamic between planetary vulnerabilities and new technologies.



Strong and weak interdependencies between the 2015 World Economic Forum Top Ten Emerging Technologies. World Economic Forum/Andrew Maynard, CC BY-NC-SA

Adding to this complexity, emerging technologies are highly interdependent on one another. AI development, for instance, affects and is affected by neuromorphic technologies, which in turn are relevant to drones, next-generation robotics and even the digital genome. This, in turn, is connected to precision genetic engineering and from there, we rapidly reconnect back to AI.

The result is a massively interconnected socio-techno-environmental system that's very complex – it leaves us vulnerable to rapid, chaotic and potentially catastrophic collapse. As with other complex systems, it's one that will appear stable and predictable – until, suddenly, it isn't. And this leaves us with a problem.



We need to think about emerging technologies – including additive manufacturing, aka 3D printing – to anticipate problems.
Creative Tools, CC BY

How to innovate responsibly

In 2013, Stilgoe, Owen and McNaughten published a framework for “responsible innovation” that could help reduce at least some of the vulnerabilities associated with a rapid rise in powerful emerging technologies. As part of a growing body of research on responsible innovation, they proposed a series of recommendations aimed at enabling innovators, policy makers and others to take care of the future through “collective stewardship of science and innovation in the present.” At the center of their recommendations were four “dimensions” of responsible innovation:

- **Anticipation** of emerging issues
- **Reflexivity** over how well or poorly existing approaches are ensuring responsible development of new technologies
- **Inclusion** of key stakeholders in making decisions
- **Responsiveness** to emergent risks and opportunities

Governments and investors are beginning to take such ideas increasingly seriously - for instance, the European Union Horizon 2020 framework program for research and innovation includes a specific work program on Responsible Research and Innovation.

Yet if we are to avoid our collective inventiveness pushing us off the metaphorical precipice of chaotic failure, much more is needed.

Crucially, we need to ensure that informed responsibility is built into the process of innovation from the ground up – starting with researchers and innovators, and continuing through investors and

consumers. Complementing this, society must stimulate and support innovation that leads to socially, economically and environmentally sustainable progress.

The greatest challenge we face however, is in moving away from considering emerging technologies in isolation, and toward understanding and responding to the highly complex, nonlinear and potentially chaotic interplay between technology innovation, society and the environment.

This pushes us into uncharted waters. Over the past decade, there's been substantial progress in understanding the risks and benefits of individual technologies such as nanotechnology, which is revolutionizing how we design new materials from atoms up, or synthetic biology, which is opening the door to digitally manipulating genetic information, and uploading it back into living organisms. Yet just as understanding a single transmission line in the Indian supply grid wouldn't have helped avert the 2012 collapse, so understanding the risks and benefits of each emerging technology in turn will not help avoid future catastrophic failure.

To build a resilient tech-based future, we need new ideas, new research and new tools that will enable us to realize the benefits of technology innovation, while keeping us a safe distance from potentially catastrophic collapse. It's a tough challenge, and one that will demand unprecedented levels of interdisciplinary investment, collaboration and creativity. Yet the price of not innovating responsibly is one that may just be too large to live with.

 Nanotechnology 3-D printing



New technologies – like these carbon nanotubes – must be developed with an eye toward how they interact with other tech. Pacific Northwest National Laboratory, CC BY-NC-SA