STANFORD UNIVERSITY

THE STANFORD EMERGING TECHNOLOGY REVIEW 2026

A Report on Ten Key Technologies and Their Policy Implications

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FOREWORD

This edition of the Stanford *Emerging Technology Review* (*SETR*) coincides with the 250th anniversary of America's Declaration of Independence. As we look toward the future, the past reminds us that history takes surprising turns and that human agency can be powerful. In 1776, few could have dreamed that a ragtag band of colonists in a backwater far from Europe would defeat a great power, replace a king with an extraordinary experiment in democracy, and ultimately become the technological envy of the world. What looked impossible two and a half centuries ago seems inevitable now. Bold ideas and determined action made all the difference.

Today, we face a hinge of history moment where technological discoveries are supercharging both possibility and risk at dizzying speed. This emerging world is hard to understand and even harder to anticipate. But this much seems clear: The choices made today, in everywhere from labs to legislatures, are likely to have consequences for generations. Artificial intelligence (AI) is poised to transform scientific discovery, the future of work, the future of war, and more. And AI is not alone. From nanomaterials that are fifty thousand times smaller than the width of a human hair to commercial satellites and other private-sector technologies deployed in outer space, breakthroughs are reshaping markets, societies, and geopolitics. This is a convergence moment: Never have so many technologies changed so much so fast.

In this era, US technology policy is no longer the unique province of government that it used to be. Federal and state officials are struggling to keep up with technological advances and their implications. At the same time, inventors and investors are struggling to reconcile commercial opportunities and national interests in a world where technology, economics, and geopolitics have become inseparable.

Now more than ever, understanding the landscape of discovery and how to harness technology to forge a better future requires working across sectors, fields, and generations. Engineers and executives need to better understand the policy world to anticipate how their decisions could generate geopolitical advantages and vulnerabilities, and how they can seize opportunities while mitigating risks to the nation. Government leaders need to better understand the academic and business worlds so that well-intended policies don't end up exacerbating societal harms or dampening America's innovation leadership and the geopolitical advantages that come with it. And both government and industry need to better understand the foundational role that America's research universities play in the ecosystem that has made the United States the world's innovation leader since 1945—and how that model is now weakening at home while China is racing to copy it.

The Stanford Emerging Technology Review (SETR) initiative is the first-ever collaboration between Stanford University's School of Engineering, the Hoover Institution, and Stanford's Institute for Human-Centered Artificial Intelligence. We launched this effort with an ambitious goal: transforming technology education for decision makers in both the public and private sectors so that the United States can seize opportunities, mitigate risks, and ensure the American innovation ecosystem continues to thrive.

This is our third annual report surveying the state of ten key emerging technologies and their implications. It harnesses the expertise of leading faculty in science and engineering fields, economics, international relations, and history to identify key technological developments, assess potential implications, and highlight what policymakers should know.

This report is our flagship product, but it is just one element of our continuous technology education campaign for policymakers that now involves more than one hundred Stanford scholars across forty departments and research institutes. In the past year, SETR experts have briefed senior leaders in the private sector and across the US government—in Congress, the White House, the Department of Commerce, the Department of Defense, and the intelligence community. We have organized and participated in dozens of Stanford programs, including multiday congressional staff boot camps in AI, biotechnology, and emerging technologies more broadly; roundtables for CEOs, national media, state and local leaders, and officials from European partners and allies; and workshops convening leaders across sectors to develop new insights that advance space policy, America's biotechnology strategy, defense innovation, and economic statecraft.

Our efforts are guided by three observations:

1. **America's global innovation leadership matters.**

American innovation leadership is not just important for the nation's economy and security. It is the linchpin for maintaining a dynamic global technology innovation ecosystem and securing its benefits for the United States and the world.

Put simply, it matters whether the global innovation ecosystem is led by democracies or autocracies. Democratic countries promote freedom and thrive in it, while authoritarian countries do not. Freedom, in turn, is the fertile soil of innovation, and it takes many forms: the freedom to criticize a government; to admit failure in a research program as a step toward future progress; to share findings openly with others; to collaborate across geographical and technical borders with reciprocal access to talent, knowledge, and resources; and to work without fear of repression, persecution, or political reprisal.

But the United States cannot succeed alone. Robust international collaboration, especially with allies and partners, is essential for bringing together the best minds to tackle the world's toughest challenges, accelerating technological breakthroughs, and advancing American values, not just our interests.

China's rise poses many challenges, and we must not be naive about the Chinese Communist Party's espionage activities and intellectual property theft from American companies and universities or its spread of repressive surveillance technologies around the world. But it is also worth remembering that international scientific collaboration has long been pivotal to fostering global peace, progress, and prosperity, even in times of intense geopolitical competition. During the Cold War, American and Soviet nuclear scientists and policymakers worked together to reduce the risk of accidental nuclear war through arms control agreements and safety measures—at the same time as their nuclear weapons were targeting each other's cities. Similarly, scientific cooperation with China is essential today for reducing shared risks posed by new technologies, from AI-enabled nuclear command and control disasters to conflict in outer space that could bring devastating unintended or unexpected consequences for commercial activities and civilian life.

2. **Academia's role in American innovation is essential—and at risk.**

America's thriving innovation ecosystem has rested on three pillars: the government, the private sector, and the academy. Success has required robust research and development (R&D) in all three. But they are not the same. Evidence suggests that universities' role as the engine of innovation is increasingly at risk, and there is no plan B.

Universities, along with US national laboratories, are the only institutions that conduct research on the frontiers of knowledge without regard for potential profit or foreseeable commercial application. This kind of research is called basic or fundamental research. It takes years, sometimes decades, to bear fruit. And it often fails, because fundamental research is in the business of asking big, hard questions to which nobody knows the answers. But without this kind of research over long periods of time, future commercial innovations would not be possible. Fundamental research investigates questions like, "What are the principles of quantum physics?" and "How does the human immune system work?" Commercial research then builds on openly published academic work to develop quantum computing start-ups whose work could help identify new materials or develop medicines that save millions of lives.

Much of our daily life depends on breakthroughs that would never exist without years of federal investment in fundamental research inside universities. The internet, radar, magnetic resonance imaging (MRI) machines, and the Global Positioning System (GPS) for navigation are just a few examples. Today's AI revolution began fifty years ago with university research into neural networks.

Everyone uses Google, but few people know that Google emerged from a National Science Foundation grant to Stanford professors who were conducting fundamental research on digital libraries back in 1993—when there were one hundred total websites on Earth.[1]

However, there are signs that the engine of innovation in US research universities is not running as well as it could, posing long-term risks to the nation and our technological leadership. In 2024, for the first time, the number of Chinese contributions surpassed ones from the United States in the closely watched *Nature* Index, which tracks eighty-two of the world's premier science journals.[2] Increasingly, the world's best and brightest are not automatically coming to the United States to be educated and possibly stay; global talent has far more educational and training options now than it did ten or twenty years ago. For example, a 2025 Hoover Institution study found that more than half of China's leading AI researchers behind DeepSeek's breakthrough large language model (LLM) were educated and trained entirely in China.[3] In today's technological era, knowledge really is power, and it starts with talent.[4] Reversing the downward slide of American K–12 education at home and recruiting and retaining the brightest minds from abroad have never been more important for American technological competitiveness and national security.

Universities have work to do to fulfill our mission of promoting serious and searching inquiry, restore civic discourse, and regain the trust of the American people. Making cosmetic changes and hoping to return to the way things were will not be enough; this is a moment to reimagine and reinvigorate higher education in service of discovery and the nation. At the same time, the current challenges across US campuses should not distract from the urgent need

Evidence suggests that universities' role as the engine of innovation is increasingly at risk, and there is no plan B.

to ensure American research universities have what it takes to make the breakthrough discoveries of tomorrow. We are harvesting today the research seeds planted decades ago. But we are not planting for the future like we once did.

The US government is the only funder capable of making large and risky investments in the basic science conducted at universities (as well as national laboratories) that is essential for future applications. Yet federal R&D funding has plummeted in percentage terms since the 1960s, from 1.86 percent of GDP in 1964 to just 0.66 percent of GDP in 2016.[5] The United States used to spend more of its GDP on science and research than any nation in the world; today the US ranks eighth.[6]

The Creating Helpful Incentives to Produce Semiconductors (CHIPS) and Science Act of 2022 was supposed to begin reversing this yearslong decline by dramatically increasing federal funding for basic research. But those increases were subsequently scrapped. Current budget proposals call for further reductions in the National Science Foundation budget (which funds all fields of fundamental science and engineering outside of medicine) and the National Institutes of Health budget (which funds medical research).

The United States still funds more basic research than China does, but China is copying the US innovation playbook by investing more and more in basic research and concentrating talent in research universities. In fact, China's basic research investment is rising six times faster than that of the United States. As figure F.1 illustrates, China is poised to overtake the US by the end of the decade if current trends continue.

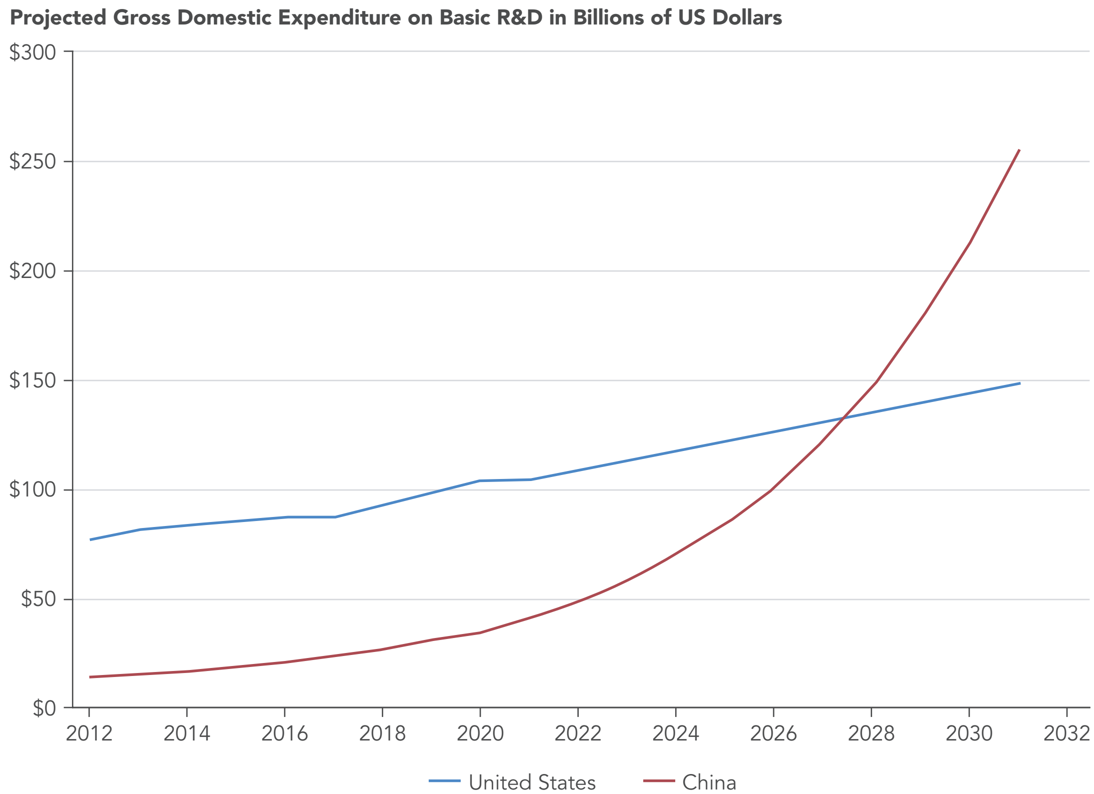
Private-sector investment in technology companies and associated university research has increased substantially over time, and it may seem like an attractive substitute. But it is not the same. Private investors (rightly) expect returns on their investment, which naturally leads them to fund research avenues with a shorter-term focus and commercial viability. Federal funding for basic research, by contrast, is directed at research that has no foreseeable profit but addresses national issues for the public benefit, seeks to advance basic understanding, and can take a longer-term view to pursue moonshot ideas.[7]

To be sure, the rising dominance of private industry in innovation brings significant benefits. But it is also generating serious and more hidden risks to the health of the entire American innovation ecosystem. In some areas, technology and talent are migrating from academia to the private sector, accelerating the development of commercial products while eroding the foundation for the future. We are already reaching a tipping point in AI. In 2022, more than 70 percent of students who received PhDs in artificial intelligence at US universities took industry jobs, leaving fewer faculty to teach the next generation.[8] As the bipartisan National Security Commission on Artificial Intelligence put it, "Talent follows talent."[9]

Today, only a handful of the world's largest companies have both the talent and the enormous compute power necessary for developing sophisticated LLMs like ChatGPT. No university comes close. In 2024, for example, Princeton University announced that it would tap endowment funds to purchase 300 advanced NVIDIA chips to use for research, costing about $9 million, while Meta announced plans to purchase 350,000 of the same chips by year's end at an estimated cost of $10 billion.[10]

These trends raise several concerning implications.[11] A very significant one is that research in the field is likely to be skewed to applications driven by commercial rather than public interests. The ability for universities—or anyone outside of the leading AI companies—to conduct independent analysis of the weaknesses, risks, and vulnerabilities of AI (especially LLMs recently in the news) will become more important and simultaneously more difficult. Further, the more that industry offers unparalleled talent concentrations, computing power, training data, and the most sophisticated models, the more likely it is that

FIGURE F.1 China is projected to overtake the United States in basic research and development spending



Note: The projection assumes the rate of change between 2012 and 2024 continues forward; it does not include the Trump administration's proposed FY 2026 budget reductions to federally funded research.

Source: OECD Main Science and Technology Indicators Dataset, https://www.oecd.org/en/data/indicators/gross-domestic-spending-on-r-d.html

future generations of the best AI minds will continue to flock there, potentially eroding the nation's ability to conduct broad-ranging foundational research in the field.

3. The view from Stanford is unique, important—and needed now more than ever.

Stanford University has a unique vantage point when it comes to technological innovation. It is not an accident that Silicon Valley surrounds Stanford; technology developed at Stanford in the 1930s served as the foundation for the pioneering companies like Varian Associates and Hewlett-Packard that first shaped industry in the Valley. Since then, the university has continued to fuel that innovation ecosystem. Stanford faculty, researchers, and former students have founded Alphabet, Cisco Systems, Instagram, LinkedIn, NVIDIA, Sun Microsystems, Yahoo!, and many other companies, together generating more annual revenues than most of the world's economies. Start-ups take flight in our dorm rooms, classrooms, kitchens, and laboratories. Technological innovation is lived every day and up close on our campus—with all its benefits and downsides. This ecosystem and its culture, ideas, and perspectives often seem a world apart from the needs and norms

Bridging the divide between the locus of American policy and the heart of American technological innovation has never been more important.

of Washington, DC. Bridging the divide between the locus of American policy and the heart of American technological innovation has never been more important.

Stanford has a rich history of policy engagement, with scholars and alumni who serve at the highest levels of government as well as institutional initiatives that bring together policymakers and researchers to tackle the world's toughest policy problems. And generations of Stanford engineering faculty, students, and staff have had profound impact through their discoveries—from the klystron, a microwave amplifier developed in the 1930s that enabled radar and early satellite communications; to the algorithms driving Google; to optogenetics, a technique pioneered in 2005 that uses light to control neurons, enabling precise studies of brain function. In this moment of technological change, we must do even more to connect emerging technologies with policy. We are proud and excited to continue this unprecedented collaboration to bring policy analysis, social science, science, medicine, and engineering together in new ways.

Today, technology policy and education efforts are often led by policy experts with limited technological expertise. The *Stanford Emerging Technology Review* flips the script, enlisting many of the brightest scientific and engineering minds at the university to share their knowledge of their respective fields by working alongside social scientists to translate their work to nonexpert audiences. We start with science and technology, not policy. And we go from there to emphasize the important interaction between science and all aspects of policy.

How to Use This Report: One Primer, Ten Major Technology Areas

This report is intended to be a one-stop shopping primer that covers developments and implications in ten major emerging technology areas: artificial intelligence; biotechnology and synthetic biology; cryptography and computer security; energy technologies; materials science; neuroscience; quantum technologies; robotics; semiconductors; and space. The list is broad by design, and it includes fields that are widely regarded as pivotal to shaping society, economics, and geopolitics today and into the future.

That said, the ten major technology areas covered in this report are nowhere near an exhaustive catalog of technology research areas at Stanford. And the list may change year to year—not because a particular technology sputtered or we got it wrong, but because categorizing technologies is inherently dynamic; because limiting this report to ten areas imposes discipline on what we cover and how deeply we go; and because we seek to highlight relationships among technologies in ways that may not be obvious. Quantum computing, for example, used to be covered in our chapter on semiconductors, but it is included in a new chapter on quantum technologies this year because of so much current interest in and concern about quantum computing, sensing, and communications. We had a separate chapter on lasers last year, but this year's report folds lasers into our crosscutting themes analysis because the field is more of an enabling technology. Of note, nine of the ten technology chapters appearing in this edition are the same from 2025, and eight of the ten are the same in all three editions of the report.

We have expanded our treatment of issues that cut across technological fields because these are both important and often overlooked. Themes include nonobvious insights that are important for decision makers to remember—like "frontier bias," which is the natural but mistaken assumption that transformational technologies sit on only the frontiers of a field. Indeed, DeepSeek AI's LLM release last year is a cautionary tale that should remind us there are many pathways to success and that not all of them require the most advanced computational resources that American technology firms currently have.

For each of the ten technology chapters, reviews of the field were led by world-renowned, tenured Stanford faculty members who also delivered seminars to faculty contributors, discussants, and SETR advisory board members within and outside their areas of expertise (bios of SETR faculty and contributors can be found at the end of this report). The SETR team also involved more than a dozen postdoctoral scholars and undergraduate research assistants who interviewed faculty across Stanford and drafted background materials.

Each technology chapter begins with an overview of the basics—the major technical subfields, concepts, and terms needed to understand how a technology works and could affect society. Next, we outline important developments and advances in the field. Then we provide an over-the-horizon view of the technology and its future development. Each chapter concludes with a policy section that covers the most crucial considerations for policymakers over the next few years. The report ends with a chapter that looks across the ten technologies, offering analysis of implications for economic growth, national security, environmental and energy sustainability, health and medicine, and civil society.

Three points bear highlighting. First, **we offer no specific policy recommendations in this report**. That is by design. Washington is littered with reports offering policy recommendations that were long forgotten, overtaken by events, or both. Opinions are plentiful. Expert insights based on leading research are not.

We aim to provide a reference resource that is both timeless and timely, an annual state-of-the-art guide that can inform successive generations of policymakers about how to think about evolving technological fields and their implications. Individual SETR faculty may well have views about what should be done. Some of us engage in policy writing and advising. But the mission of this collective report is informing, not advocating. We encourage readers interested in learning more about specific fields and policy ideas to contact our team at SETReview2026@stanford.edu.

Second, **SETR offers *a* view from Stanford, not *the* view from Stanford**. There is no single view of anything in a university. Faculty involved in this report may not agree with everything in it. Their colleagues would probably offer a different lay of the technology landscape with varying assessments about important developments and over-the-horizon issues. This report is intended to reflect an informed judgment about the state of these ten fields—guided by SETR's faculty.

Third, **this report is intended to be the introductory product that translates a broad swath of technological research for nontechnical readers**. Other SETR offerings provide deeper dives into specific technological areas that should be of interest for subject-matter experts.

Ensuring continued American leadership in science and technology is essential, and it's a team effort. We hope this third edition of the *Stanford Emerging Technology Review* continues to spark meaningful dialogue, better policy, and lasting impact. The promise of emerging technology is boundless if, like our founding fathers, we are willing to pursue bold ideas and take determined action.

Condoleezza Rice
Jennifer Widom
Amy Zegart

Co-chairs, Stanford Emerging Technology Review

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EXECUTIVE SUMMARY

Emerging technologies have never been more important or difficult to understand. Breakthrough advances seem to be everywhere, from ChatGPT to the COVID-19 mRNA vaccines to constellations of cheap commercial shoebox-size satellites that can track events on Earth in near-real time. This is a pivotal technological moment offering both tremendous promise and unprecedented challenges. Policymakers need better expert resources to help them understand the burgeoning and complex array of technological developments—more easily and more continuously.

The *Stanford Emerging Technology Review* (*SETR*) is designed to meet this need, offering an easy-to-use reference tool that harnesses the expertise of Stanford University's leading science and engineering faculty in ten major technological areas.

SETR 2026 FOCUS TECHNOLOGIES

Artificial Intelligence
Biotechnology and Synthetic Biology
Cryptography and Computer Security
Energy Technologies
Materials Science
Neuroscience
Quantum Technologies
Robotics
Semiconductors
Space

These particular fields were chosen for this report because they leverage areas of deep expertise at Stanford and cover many critical and emerging technologies identified by the Office of Science and Technology Policy in the White House and by other US government departments. However, *SETR* focus technologies are likely to change over time. This is not because we were incorrect but because science and technology never sleep, the borders between fields are porous, and different people categorize similar research in different ways.

Report Design

This report is organized principally by technology, with each area covered in a stand-alone chapter that gives an overview of the field, highlights key developments, offers an over-the-horizon view of important technological issues, and reviews key policy considerations. Although these chapters can be read individually, one of the most important and unusual hallmarks of this moment is convergence: Emerging technologies are intersecting and interacting in a host of ways, with important implications for policy. We examine these broader dynamics in chapters 11 and 12. In chapter 11, we describe a number of themes and commonalities that cut across many of the technologies we describe earlier in the report. In chapter 12, we consolidate technological developments across all ten areas and discuss how they apply to five policy domains: economic growth, national security, environmental and energy sustainability, health and medicine, and civil society.

Three tensions run throughout and are worth keeping in mind:

- **Timeliness and timelessness** Each chapter seeks to strike a balance between covering recent developments in science and the headlines, and providing essential knowledge about how a field works, what is important within it, and what challenges lie ahead.

- **Technical depth and breadth** This report intentionally skews toward breadth, offering a thirty-thousand-foot view of a vast technological landscape in one compendium. Readers should consider it an introductory course. Other products and educational tools released in the future will offer additional insights into each field.

- **Technical and nontechnical aspects of innovation** We start with the science but do not end with the science. Technological breakthroughs are necessary but not sufficient conditions for successful innovation. Economic, political, and societal factors play enormous and often hidden roles. Johannes Gutenberg invented the printing press in 1452, but it took more than 150 years before the Dutch invented the first successful newspapers. This was not because they perfected the mechanics of movable type but because they decided to use less paper, making newspapers sustainably profitable for the first time. Each chapter in this report was written with an eye toward highlighting important economic, political, policy, legal, and societal factors likely to impede, shape, or accelerate progress.

Technologies and Takeaways at a Glance

Artificial Intelligence

Artificial intelligence (AI) is a computer's ability to perform some of the functions associated with the human brain, including perceiving, reasoning, learning, interacting, problem-solving, and even exercising creativity. In the past year, some of the main AI-related headlines focused on the rapid evolution of the field, including in areas such as large language models and multimodal models integrating vision and language, and on AI's growing adoption by both good and bad actors in society.

KEY CHAPTER TAKEAWAYS

- AI is a foundational technology that is supercharging other scientific fields and, like electricity and the internet, has the potential to transform societies, economies, and politics worldwide.

- Despite rapid progress in the past several years, even the most advanced AI models still have many failure modes and vulnerabilities to cyberattacks that are unpredictable, not widely appreciated nor easily fixed, and capable of leading to unintended consequences.

- Nations are competing to shape the global rules and standards for AI, making interoperability, sizeable national compute resources, and international governance frameworks critical levers of geopolitical influence.

Biotechnology and Synthetic Biology

Biotechnology is the use of cellular and biomolecular processes to develop products or services. Synthetic biology is a subset of biotechnology that involves using engineering tools to modify or create biological functions—like creating a bacterium that can glow in the presence of explosives. Synthetic biology is what created the COVID-19 mRNA vaccine in record time (although the effort relied on decades of earlier research). Just as rockets enabled humans to overcome the constraints of gravity to explore the universe, synthetic biology is enabling humans to overcome the constraints of lineage to develop new living organisms.

KEY CHAPTER TAKEAWAYS

- Biotechnology is emerging as a general-purpose technology by which anything bioengineers learn to encode in DNA can be grown whenever and wherever needed—essentially enabling the production of a wide range of products through biological processes across multiple sectors.
- The United States is still not executing well on strategies for emerging biotechnology and has relied too heavily on private-sector investment to support foundational work needed to scale and sustain progress.
- Biotechnology is one of the most important areas of technological competition between the United States and China, and China is now leveraging two decades of strategic investment to secure global leadership. Absent swift and ambitious actions, the United States risks biotechnological surprise and a loss of biotechnology sovereignty.

Cryptography and Computer Security

The word *cryptography* originates from Greek words that mean "secret writing." In ancient times, cryptography involved the use of ciphers and secret codes. Today, it relies on sophisticated mathematical models to protect data from being altered or accessed inappropriately. Cryptography is often invisible, but it is essential for most internet activities, such as messaging, e-commerce, and banking. In recent years, a type of cryptographic technology called blockchain—which records transactions in distributed ledgers in the computing cloud that cannot be altered retroactively without being detected—has been used for a variety of applications. These include time stamping and ensuring the provenance of information, identity management, supply chain management, and cryptocurrencies.

KEY CHAPTER TAKEAWAYS

- Cryptography is essential for protecting information, but alone it cannot secure cyberspace against all threats; it must operate in concert with the broader field of computer security.
- Cryptography is the enabling technology of blockchain, which is the enabling technology of cryptocurrencies.
- Rather than pursue a central bank digital currency, the United States has adopted a policy preference for privately issued digital assets, promoting stablecoins and cryptocurrencies as vehicles for financial innovation and resilience.

Energy Technologies

Energy is a vital strategic resource for nations that typically involves generation, transmission, and storage. Success in managing energy issues will depend on tackling the "energy trilemma," which is the task of balancing affordability and reliability with reduced greenhouse gas emissions. Energy mix and innovation are key to efforts addressing all three aspects of the trilemma. An important policy issue is achieving greater national consensus about energy goals to enable strategic and effective research and development (R&D) programs and funding.

KEY CHAPTER TAKEAWAYS

- Although many clean energy technologies are now available and increasingly affordable, scaling them up and building the infrastructure for them will take decades due to infrastructure inertia, stakeholder complexity, and the "energy trilemma," which balances reliability, affordability, and cleanliness.

- The US has shifted from climate urgency to energy dominance, redirecting support from renewables and electric vehicles to fission, coal, and natural gas. Globally, similar trends prevail as nations record peak fossil fuel use and scale back renewable investments, prioritizing energy security over decarbonization.

- Energy innovation is fragmented, diverse, and geopolitically strategic, with progress in technologies like fission, geothermal, fusion, and batteries reshaping the energy frontier. To compete with China, US technology leadership depends on sustained R&D funding, robust supply chains, and strategic industrial policies.

Materials Science

Materials science studies the structure and properties of materials—from those visible to the naked eye to microscopic features—and how they can be engineered to change performance. Contributions to the field have led to better semiconductors, "smart bandages" with integrated sensors and simulators to accelerate healing, more easily recyclable plastics, and more energy-efficient solar cells. Materials science has also been key to the development of additive manufacturing, often known as 3-D printing.

KEY CHAPTER TAKEAWAYS

- Materials science is a foundational technology that underlies advances in many other fields, including robotics, space, energy, and synthetic biology.

- The field will exploit artificial intelligence as another promising tool to predict new materials with new properties and to identify novel uses for known materials.

- Future progress in materials science requires new funding mechanisms and access to additional computational power to more effectively transition from innovation to implementation.

Neuroscience

Neuroscience is the study of the human brain and the nervous system—its structure, function, healthy and diseased states, and life cycle from embryonic development to degeneration in later years. The brain is perhaps the least understood and yet most important organ in the human body. Three major research subfields of neuroscience are neuroengineering (e.g., brain–machine interfaces), neurohealth (e.g., brain degeneration and aging), and neurodiscovery (e.g., the science of addiction).

KEY CHAPTER TAKEAWAYS

- Advances in human genetics and experimental neuroscience, along with computing and neuroscience theory, have led to some progress in several areas, including understanding and treating addiction and neurodegenerative diseases, and designing brain–machine interfaces for restoring vision.

- American leadership is essential for establishing and upholding global norms about ethics and human subjects research in neuroscience, but this leadership is slipping with decreased strategic planning and increased foreign investments in the field.

- Popular interest in neuroscience vastly exceeds the current scientific understanding of the brain, giving rise to overhyped claims in the public domain that revolutionary advances are just around the corner.

Quantum Technologies

Quantum technologies exploit the unusual principles of quantum mechanics, such as superposition and entanglement, to create new capabilities in computing, communication, and sensing. Quantum computers are moving toward solving problems that classical systems cannot, with applications in cryptography, materials science, and chemistry. Quantum networking may enable secure communications and scalable computing, while quantum sensors are already advancing navigation, medicine, and environmental monitoring. Though quantum technology (especially computing) is still relatively early in its development, global investment is accelerating, making sustained research and careful policymaking essential to balance innovation, security, and competition.

KEY CHAPTER TAKEAWAYS

- Quantum computing is advancing rapidly, making clear progress toward solving practical problems such as breaking existing public-key encryption algorithms, enabling new materials design, and supporting applications in chemistry. More speculative uses include machine learning, weather modeling, and financial portfolio optimization.

- Quantum networking and sensing are emerging as powerful technologies—networking may be critical for scaling computers to utility levels, while sensors are already transforming fields such as medical imaging and gravitational detection.

- Government-funded basic research in academic labs remains the foundation for breakthroughs, and sustained investment is essential to maintain leadership as companies push applications toward real-world utility.

Robotics

Robotics is an integrative field that draws on advances in multiple technologies rather than a single discipline. The question "What is a robot?" is harder to answer than it appears. At a minimum, the emerging consensus among researchers is that a robot is a physical entity that has ways of sensing itself and the world around it and can create physical effects on that world. Robots are already used across a range of sectors in a variety of ways—including assembly-line manufacturing, space exploration, autonomous vehicles, tele-operated surgery, military reconnaissance, and disaster assistance.

KEY CHAPTER TAKEAWAYS

- Artificial intelligence holds significant potential to advance complex robotic systems, but the speed of future advances will depend on the availability of high-quality training data and the systematic integration of data-rich foundation models, simulated interactions between robots and their environment, and understanding of the real physical world.

- Humanoid robots show promise for specialized industrial and healthcare roles, although widespread adoption of them faces challenges linked to their cost, technical complexity, energy efficiency, safety, and training data quality.

- Advances in autonomous, low-cost, and communication-resilient robotic systems are transforming important aspects of modern warfare.

Semiconductors

Semiconductors, or chips, are crucial and ubiquitous components used in everything from refrigerators and toys to smartphones, cars, computers, and fighter jets. Chip production involves two distinct steps: (1) design, which requires talented engineers to design complex integrated circuits involving millions of components, and (2) fabrication, which is the task of manufacturing chips in large, specially designed factories called "fabs." Because fabs involve highly specialized equipment and facilities, they can cost billions of dollars. US companies still play a leading role in semiconductor design, but capacity for semiconductor manufacturing in America has plummeted, leaving the country heavily dependent on foreign chips, most notably from Taiwan. The Creating Helpful Incentives to Produce Semiconductors (CHIPS) and Science Act of 2022 was intended to help the US semiconductor industry regain a foothold in fabrication, but progress will take years, if not decades.

KEY CHAPTER TAKEAWAYS

- The growing demand for artificial intelligence (AI) and machine learning is driving innovations in chip fabrication, along with advances in memory technologies and high-bandwidth interconnects such as photonic links, all of which are essential for enhancing computational power, managing energy efficiency, and meeting the increasing data needs of modern applications.

- Semiconductor manufacturing is the most precise manufacturing process that exists. It is used to advance work in energy and biotechnology in addition to information technology and AI.

- Strategic technology containment efforts directed against China help constrain Chinese capabilities in the short term. However, they are likely to drive China into a technology posture that is considerably more decoupled from the West and hence less vulnerable to Western pressure in the future.

Space

Space technologies include any technology developed to conduct or support activities approximately sixty miles or more beyond Earth's atmosphere. A single space mission is a system of systems—including everything from the spacecraft itself to propulsion, data storage and processing, electrical power generation and distribution, thermal control to ensure that components are within their operational and survival limits, and ground stations. While in the past, space was the exclusive province of government spy satellites and discovery missions, the number and capabilities of commercial satellites have increased dramatically in recent years. There were roughly one thousand total active satellites in orbit in 2014; today there are around eleven thousand—a figure that will likely rise to several tens of thousands in the next decade.

KEY CHAPTER TAKEAWAYS

- A burgeoning "NewSpace" economy driven by private innovation and investment is transforming space launch, in-space logistics, communications, and key space actors in a domain that until now has been dominated by superpower governments.

- Space is a finite planetary resource. Because of dramatic increases in satellites, debris, and geopolitical space competition, new technologies and new international policy frameworks will be needed to manage the traffic of vehicles, prevent international conflict in space, and ensure responsible stewardship of this global commons.

- The Trump administration has shifted priorities heavily toward human exploration of the Moon and Mars. This is at the expense of robotic exploration, space science, and aeronautics missions, leading to significant planned budget and personnel cuts to NASA. This trend may risk the long-term superiority of the United States in the global race for talent and technology.

Important Crosscutting Themes

Chapter 11 discusses fifteen themes that cut across the technological areas. We split these themes into four categories.

- **Governance and Geopolitics of Emerging Technology** examines how governments and political systems shape global technological progress.
  - Innovation that emerges too fast threatens the legitimate interests of those who might

be negatively affected, while innovation that moves too slowly increases the likelihood that a nation will lose first-mover advantages.

- National monopolies on technology are increasingly difficult to maintain. Even innovations that are solely American born (an increasingly rare occurrence) are unlikely to remain in the exclusive control of American actors for long periods.
- The US government is no longer the primary driver of technological innovation or funder of research and development (R&D).
- While democracies provide greater freedom for scientific exploration, authoritarian regimes can direct sustained funding and focus on technologies they believe are most important.

Innovation Pathways and Patterns of Progress explores the diverse ways in which technological progress unfolds.

- Technological progress is often unpredictable and nonlinear, with periods of slow development interrupted by sudden breakthroughs. While some fields, like semiconductors, have shown steady improvement, most technologies advance through cycles of experimentation, feedback, and convergence of multiple innovations.
- Nonscientific factors, such as engineering feasibility, economic viability, manufacturing challenges, and societal acceptance, influence the adoption of technology based on scientific advances.
- Hype can distort perceptions, leading to inflated expectations that outpace practical utility and distortions in resource allocation.
- Frontier bias causes overemphasis on new technologies and sometimes results in overlooking impactful uses of established ones.
- The synergies between different technologies are large and growing, which makes understanding the interactions between different fields all the more important.

Human Capital and Knowledge Ecosystems highlights the critical roles of people, universities, and funding structures in driving and sustaining innovation.

- Human capital is the foundation of scientific and technological progress. Sustained investment in it is the single most critical factor in ensuring long-term national competitiveness and scientific advancement.
- Universities are central to both high-risk research and science, technology, engineering, and mathematics (STEM) education. Yet federal R&D funding as a share of GDP has declined, and policy ambiguities hinder international collaboration.
- The "valley of death" between research feasibility and commercial viability remains a major barrier to advancing innovations to market. New funding models are needed to bridge this gap and sustain America's technological leadership.

Infrastructure for Innovation encompasses vital systems and structures that support innovation on a large scale.

- Standards enable interoperability, lower costs, and support global trade but can also stifle innovation and be manipulated for market control or geopolitical advantage.
- Manufacturing is vital for economic resilience and security, especially amid global supply chain disruptions and strategic competition with China and other nations. Technological advances like robotics and artificial intelligence are reshaping production, while

policies such as the CHIPS and Science Act of 2022 aim to boost domestic capacity.

- Cybersecurity protects data, systems, and intellectual property from threats, ensuring research integrity and confidentiality. However, maintaining robust security can conflict with the open culture of research environments.

Finally, each of the ten technology fields covered in this report bears on five policy areas that are of interest to policymakers: economic growth, national security, environmental and energy sustainability, health and medicine, and civil society. Chapter 12 identifies applications and consequences of each field as they apply to these policy areas.