Compete.
Council on Competitiveness

2018 Clarion Call

Launch of the National Commission on Innovation and Competitiveness Frontiers

More than any country in history, the United States has been the greatest driver and beneficiary of technology, innovation and a vibrant entrepreneurial spirit. In the 19th century, entrepreneurs and innovations surrounding agriculture, rail, oil, steel and electricity turned the United States into an industrial and economic powerhouse, laying the foundation for a manufacturing sector that provided middle class jobs and a higher standard of living for millions of Americans. In the 20th century, American inventions and advancements in vehicle and aircraft technology revolutionized transportation, and changed society and the geographic face of the country. American-born digital technologies unleashed a revolutionary new age of computing, communications and information mobility, disrupting industries and business models, changing society and culture around the world, and creating enormous new wealth. This continuum of innovation has delivered prosperity and rising standards of living to Americans, and propelled the United States to global leadership.

The Council on Competitiveness (Council) has long characterized the competitive landscape, and examined where America stands. When major competitive opportunities or challenges emerge, the Council has sought to bring those to national attention, explore their implications and develop recommendations for action. Notwithstanding a currently robust economy—rising and strong economic, productivity and job growth; historically low unemployment; wage increases; an improved tax environment; etc.—the Council believes U.S. leadership in technology and long-term competitiveness are under threat. This potential demands the urgent attention of our nation's leaders, and a focused examination of our capabilities, investments and policies related to science, technology development and innovation.

A New Sputnik Moment?

The United States emerged from World War II confident as the world's superpower. Americans were enjoying a post-war economic boom, an expanding middle-class and rising incomes. But, on October 4, 1957, the Soviet Union successfully launched Sputnik 1, the world's first artificial satellite. Caught off guard, the public stood on front porches and in back yards scanning the night sky, unnerved and worried about the satellite's implications. The launch created a crisis of confidence in American technology, political leadership and the military.

But the launch also galvanized the country. The United States entered a scientific and technological Space Race against the Soviets, scaling-up a massive space program, and accomplishing one of the most ambitious and audacious feats of engineering in human history, the Apollo Program—landing a man on the moon and returning him safely to earth. It involved the largest commitment of resources ever made by any nation in peacetime, a total of $19.4 billion by the program's completion, or about $140 billion in today's dollars.[1] Young Americans were inspired to help America win the Space Race, firing off hobby rocketry, and pursuing science and math studies with new vigor.

> "No event since Pearl Harbor set off such repercussions in public life."
>
> **Walter McDougall**
> Historian

The U.S. space program drove numerous technology developments and helped pave the way for U.S. dominance in aerospace technologies and global markets. Today, the United States has a 53 percent share of global value-added in aircraft and spacecraft manufacturing; the next largest producer, the United Kingdom, has a 9 percent share.[2]

However, while the United States is enjoying an economic upswing on many fronts, U.S. leadership in technology is under renewed threat. In 1960, the United States dominated global research and development (R&D), accounting for a 69 percent

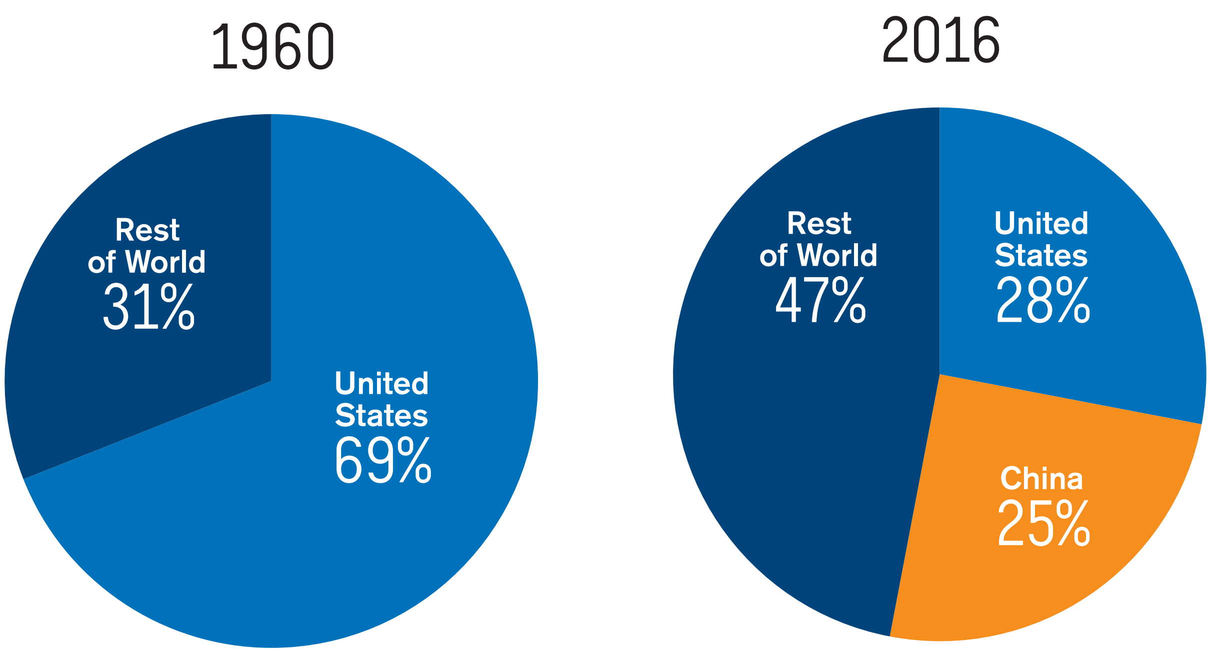
1. Apollo Program Budget Appropriations, https://history.nasa.gov/SP-4029/Apollo_18-16_Apollo_Program_Budget_Appropriations.htm; NASA Langley Research Center's Contributions to the Apollo Program, NASA Fact Sheet.
2. Science and Engineering Indicators 2018, National Science Foundation.

share of the world's R&D investment. The United States could drive developments in technology globally by virtue of the size of its investment. Today, we have evolved into a multipolar science and technology world. As other nations have increased their R&D investments and capacity for innovation, the U.S. share of global R&D expenditures has dropped to 28 percent in 2016, diminishing the U.S. dominance and leverage over the direction of technology advancement, and China has risen to account for a quarter of global R&D spending (Figure 1).

In addition, America's lead in venture capital is shrinking, further diminishing its role as a driver of technology and innovation globally. In 1992, U.S. investors led 97 percent of the $2 billion in venture finance, and accounted for about three-quarters just a decade ago. However, in 2017, U.S. investors led 44 percent of a record $154 billion in venture finance, with Asian investors (with China leading) accounting for 40 percent.[3] Moreover, while the absolute level of venture capital coming to the United States has increased substantially, the U.S. share of the growing global pool of venture capital—which has

Figure 1. U.S. Share of Global R&D Expenditures

Sources: U.S. Department of Commerce, Office of Technology Policy, *The Global Context for U.S. Technology Policy*, Summer 1997; OECD Main Science and Technology Indicators.



3. Silicon Valley Powered American Tech Dominance—Now it has a Challenger, Wall Street Journal, April 12, 2018.

The generally vigorous pace at which total global R&D has increased, more than two and a half times over the 2000–2015 period and continuing to grow, remains among the most prominent developments—a continued reflection of the escalating knowledge intensiveness of the economic competition among the world's nations.

National Science Foundation
Science and Engineering Indicators 2018

increased by more than 200 percent since 2010—has dropped sharply from 95 percent in the early 1990s, to about half in 2017.[4]

While traditional U.S. competitors—such as Germany, Japan, France and the U.K.—continue to be strong R&D performers working at the leading edge of technology, many emerging economies seek to follow the path of the world's innovators, transform to knowledge-based economies, and drive their economic growth with technology and innovation. A growing number of emerging economies are establishing government organizations and ministries focused on technology and innovation, adopting innovation-based growth strategies, boosting government R&D investments, and developing research parks and regional centers of innovation. Some of these economies are also working to increase their production of scientists and engineers. These actions are raising technology development capabilities and innovation capacity around the world.

Most notable for its rapidly strengthening position, China poses an especially formidable and growing strategic competitive challenge. For example, China has exhibited dramatic growth in its investment in R&D, more than doubling since 2010, reaching $451 billion in 2016, second only to the U.S. investment, and set to outpace the United States by the end of this decade (Figure 2).

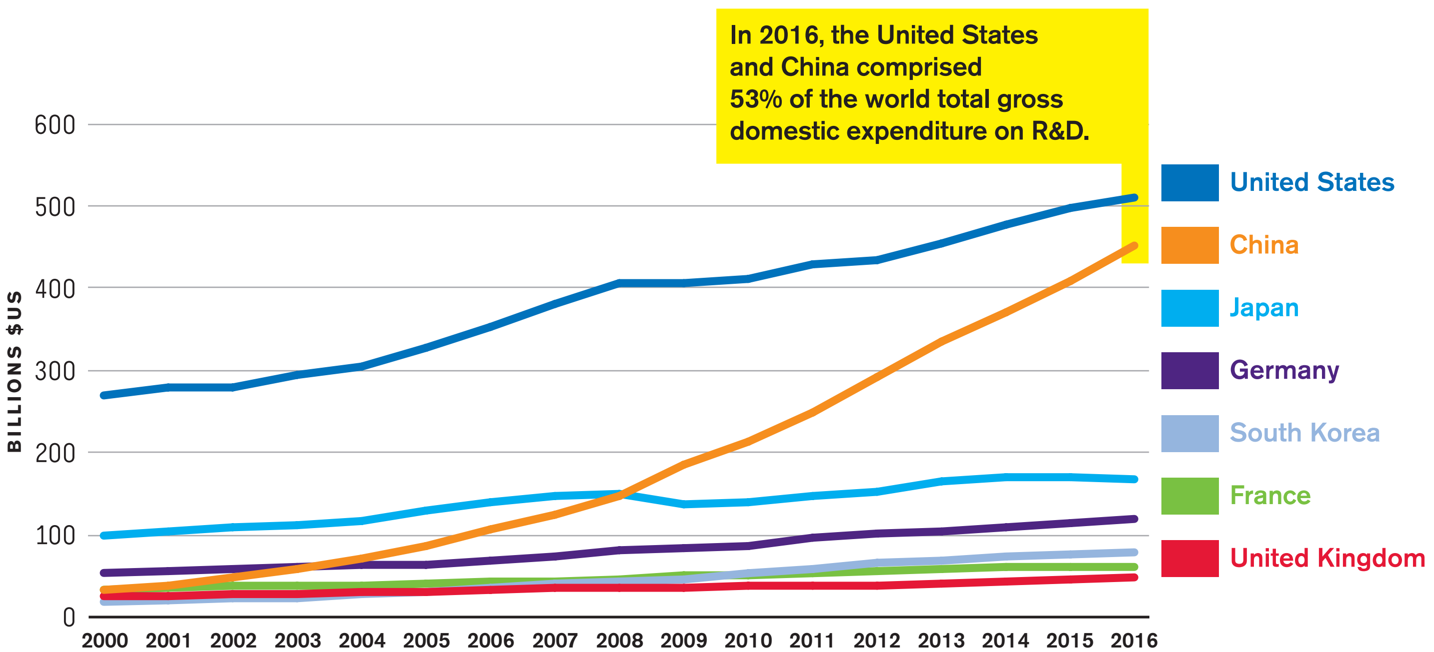
With a 31 percent global share, the United States remains the world leader in the manufacture of high-tech products (aircraft and spacecraft; computers, communications and semiconductors; testing, measuring and control instruments; and pharmaceuticals), and our output is growing. However, China has a 24 percent share; its output is also growing, surpassing Japan and the EU, and it is closing the gap with the United States.[5]

China is pursuing aggressive plans to dominate the next generation of technology. National policies—such as the 13th Five-Year Plan on National Scientific and Technological Innovation, and the Made in China 2025 Plan—are concerted efforts to cultivate indigenous technological innovation, backed by commitments for hundreds of billions of dollars in investment.

4. Rise of the Global Startup City, the New Map of Entrepreneurship and Venture Capital, by Richard Florida and Ian Hathaway, Center for American Entrepreneurship, 2018.

5. Science and Engineering Indicators 2018, National Science Foundation.

Figure 2. Gross Domestic Expenditure on R&D, 2000–2016
Source: OECD Main Science and Technology Indicators



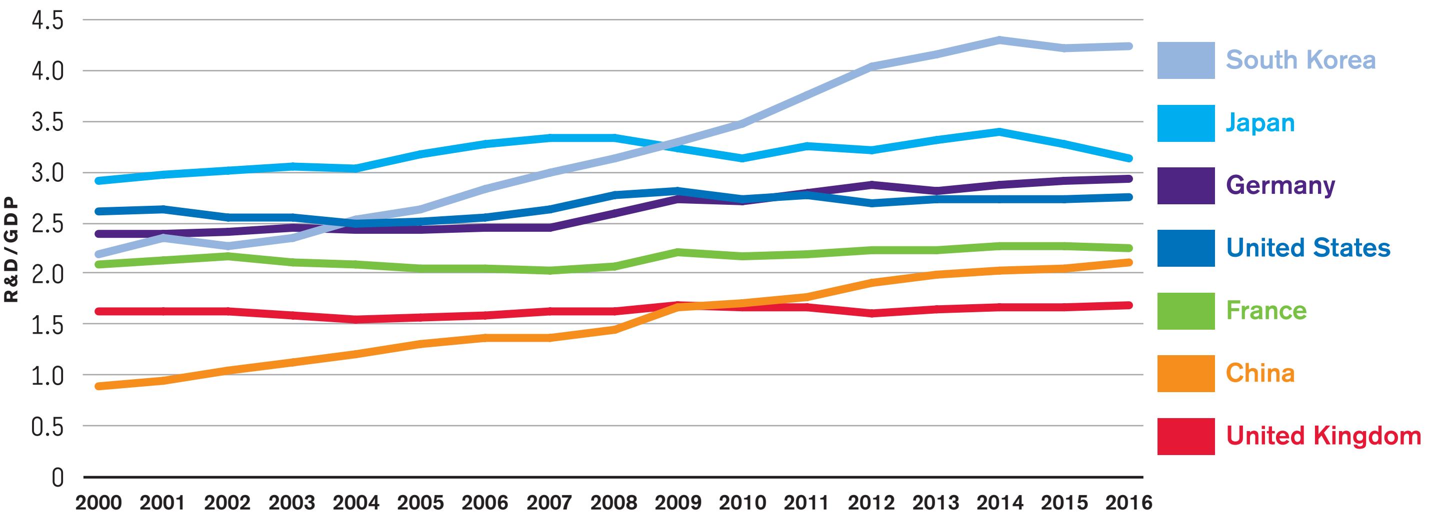
A nation's R&D intensity, expressed as R&D expenditures as a percentage of GDP, provides another gauge of national R&D performance. In this measure, the U.S. position globally has lagged in recent years, as other countries have expanded the range and scope of their R&D activities. Notably, South Korea, one of the world's largest R&D performers and another formidable U.S. competitor, ranks at the top in this metric (Figure 3).

Key U.S. science and technology infrastructure is eroding. Much like roads, rail and power plants were essential for the Industrial Age, infrastructure that supports knowledge creation and technology development is vital for the 21st century knowledge economy and U.S. success in innovation-based global competition. This includes laboratories, research and technology demonstration centers, supercomputers, test-beds, wind tunnels, propulsion and combustion facilities, simulators, accelerator and other user facilities.

America's national laboratory system is considered a distinctive and globally unique competitive asset. But, across the system, core scientific and technological capabilities are potentially at risk due to deficient and degrading infrastructure. Space in many facilities within the system is old, outdated, even obsolete, with maintenance and repair hamstrung by chronic underfunding, and maintenance backlogs in the hundreds of millions of dollars.

Figure 3. Gross Expenditure on R&D as Percentage of GDP

Source: OECD Main Science and Technology Indicators



For example, the Department of Energy (DOE) has a vast portfolio of world-leading scientific infrastructure and production assets developed over the past 75 years, including 17 national laboratories. With a replacement plant value of more than $130 billion, the land, facilities and other assets that comprise this infrastructure represent some of America's premier assets for science, technology, innovation and security. This infrastructure is degrading with only about half of DOE-owned buildings and trailers rated as adequate to meet the mission, and levels of deferred maintenance continue to rise, putting core capabilities in areas such as bioenergy research, materials and chemical science and technology, mechanical and thermal engineering, climate and atmospheric science, and biological systems science at risk.[6]

At the National Institute of Standards and Technology (NIST), more than half of the facilities on its two main campuses are in poor to critical condition. Forty-two percent of the space in its Boulder facilities is outdated or obsolete, with older laboratories there unable to support controlled environments required for advanced research. Other NIST facilities have experienced water damage, electrical failures and power outages. Facilities in poor to critical condition include those with capabilities in engineering mechanics, metrology, physics, materials, fluid mechanics and buildings research.[7]

At NASA, about 82 percent of infrastructure and facilities are beyond their constructed design life. NASA facilities have experienced water intrusions that have damaged structures, infrastructure and

6. Annual Infrastructure Executive Committee Report to the Laboratory Operations Board, U.S. Department of Energy, March 27, 2018.

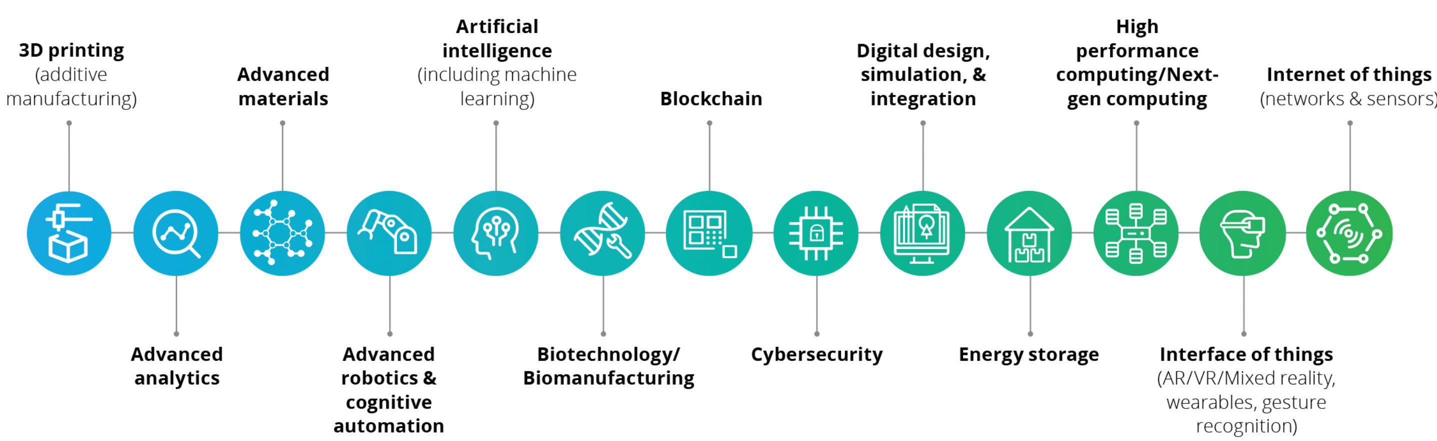
7. NIST Boulder Facilities Update, Office of Facilities and Property Management, October 2018; NIST Facilities Overview, Presentation before the NIST Visiting Committee on Advanced Technology, June 5, 2018.

highly sensitive equipment; building flooding from rain and snow melt; and failures of high-pressure air piping.[8]

The crown jewel facilities in the national laboratory system are vital to U.S. global leadership across numerous science and technology disciplines.

In addition to rising global competition, an expanding flow of powerful new technologies is shaping the 21st century economy and altering society, while models of innovation to leverage technology for economic impact are changing (Figure 4). At the same time U.S. global leadership in technology is under threat, numerous technological revolutions are unfolding, and technology advancement is accelerating. For example, the duration of product life-cycles declined across all industries by 24 percent between 1997 and 2012.[9] In addition, the Nation faces a fundamental change in how it pursues innovation. New business models are emerging, challenging the traditional models of innovation, technology development and commercialization; cutting the linkages between production and capital; and increasing the pace of innovation by erasing boundaries between fields, sectors and disciplines. It is now possible for someone to imagine, develop and scale a disruptive technology independent of traditional institutions of innovation.

Figure 4. A Snapshot of Exponential and Disruptive Technologies Driving Innovation
Source: *Exponential Technologies in Manufacturing, 2018*, Council on Competitiveness, Deloitte and Singularity University.



8. FY 2019 Budget Estimates, National Aeronautics and Space Administration.

9. World Economic Forum Global Competitiveness Report, 2016–2017.

Clarion Call to Action

Given the United States' development as a nation, and the inextricable links between science and technology, and U.S. prosperity, standards of living, national security, modern society and geopolitical standing, every American should be concerned with the U.S. position in science, technology and innovation.

With rising and rapidly strengthening global competition, and the rapid unfolding of multiple revolutions in science and technology, a dynamic cycle of creation, growth, disruption, decline and destruction will continue into the future as economies at home and abroad reorganize around new technology. There will be opportunities for new businesses, industries and jobs, but there will also be pain for some people and communities as industries shift, labor markets are disrupted, jobs change and automation increases.

In this "Sputnik Moment," the Council on Council on Competitiveness believes the United States must make much greater and more strategic use of science and technology, and must raise innovation on the national economic agenda.

The Council has explored many of these changes in technology and innovation, and their implications for U.S. companies and the workforce. Recent efforts include but are not limited to:

- The **Exploring Innovation Frontiers Initiative**, a partnership with the National Science Foundation to understand better how innovation is changing, including the role of universities in R&D, entrepreneurship and spurring high-tech start-ups.
- *Exponential Technologies in Manufacturing*, developed in partnership with Deloitte and Singularity University, explores how exponential technologies—technologies that enable change at a rapidly accelerating, nonlinear pace—are transforming the future of manufacturing and how manufacturing companies can best tap into this disruptive shift to evolve, grow and thrive.
- *Work: Thriving in a Turbulent, Technological and Transformed Global Economy*, an analysis of important long-term trends affecting the U.S. labor market, and the challenges and opportunities they present for American workers in the fast-paced, knowledge-based, technology intensive economy that has evolved in the United States.
- The **Technology Leadership and Strategy Initiative**, a ten-year dialogue with nearly 50 Chief Technology Officers from industry, academia and the national laboratories about how to ensure U.S. technology leadership in the 21st century.
- The **Energy and Manufacturing Competitiveness Partnership**, a multi-year, research and policy effort to capture the disruptions across the energy and manufacturing sectors and to put forth a road map, *Accelerate*, for policymakers to follow.

The New Disruptors

At the same time that competition in technology and innovation is rising around the world, and U.S. technology leadership is under threat, we are witnessing the unfolding and accelerated advancement of the greatest revolutions in science and technology: a new phase of the digital revolution characterized by vast deployment of sensors, the Internet of Things, artificial intelligence (AI) and the big data tsunami; biotechnology and gene-editing; nanotechnology; and autonomous systems. Each of these technologies has numerous applications that cut-across industry sectors, society and human activities. Each is revolutionary, each is game-changing in its own right. But they are now colliding and converging on the global economy and society **simultaneously**, with profound implications for U.S. economic and national security.

These technologies are disrupting industries across the globe, as well as shaping how humans will progress and how society will advance. They are crucial drivers of productivity and economic growth, altering the patterns of society and many dimensions of everyday life. For countries and companies, the ability to leverage these technologies for economic impact is fundamental to their competitiveness and economic success.

In addition to their economic potential, these technologies could solve many of the world's critical challenges surrounding areas such as health, energy and sustainability, clean water, and the global food supply.

Biotechnology

The Human Genome Project which sequenced the first human genome took 13 years and a U.S. contribution of $2.7 billion.[10] Today, you can sequence a human genome in about a day at a cost you can pay for on a credit card (Figure 5). Advances in genetic testing and editing are turning science fiction into reality.

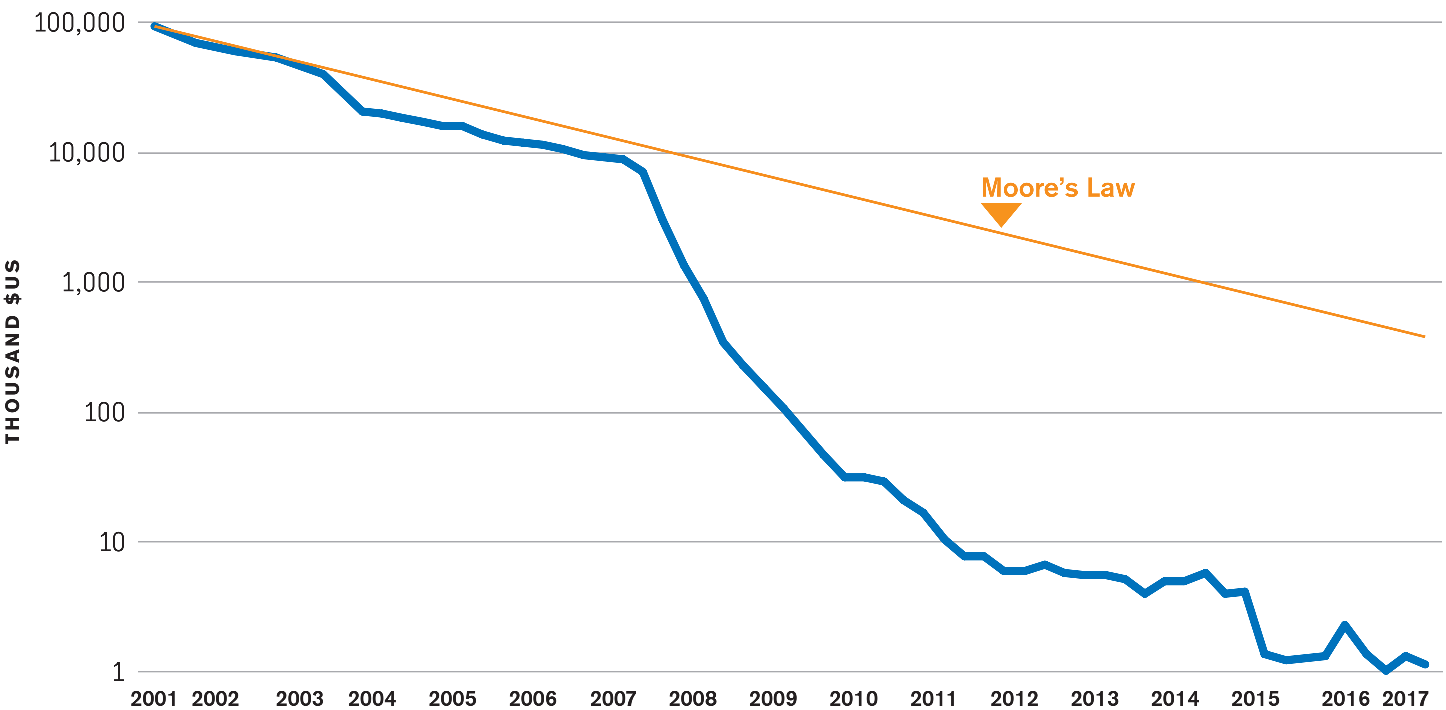
Millions of people world-wide have had their genomes sequenced and analyzed for genetic health risks and ancestry. Researchers and businesses in pharmaceuticals, healthcare, food and agriculture are leveraging these dramatic cost reductions. New gene-editing technology such as CRISPR-Cas9 is taking biotech to the next level with, theoretically, the ability to cut and paste bits of DNA into the genome of any living thing with unprecedented precision and efficiency. This technology is revolutionizing biological research and accelerating the rate at which medical, health, industrial, environmental and agricultural applications are developed. Research is being carried out globally and published at breakneck pace. Some believe this technology could cure any genetic disease, and become a major factor in ecology and environmental conservation.

Synthetic biology—the ability to modify or create novel biological organisms not found in nature—is emerging. While gene-editing makes relatively small changes to an organism's DNA, in synthetic biology, scientists stitch together long stretches of DNA and

10. In FY 1991 dollars. The Human Genome Project Completion, Frequently Asked Questions, National Human Genome Research Institute, National Institutes of Health.

Figure 5. Cost Per Genome

Source: National Human Genome Research Institute, genome.gov/sequencingcosts.



insert them into an organism's genome, or synthesize an organism's entire genome.[11] Redesigning organisms so they produce a substance, such as a medicine or fuel, or gain a new ability, such as sensing something in the environment, are common goals of synthetic biology projects. For example, using an enzyme from fireflies, scientists created a modified plant that glows in the dark that could one day replace street lights.[12] Others are working to create textiles by engineering spider silk genes into yeast.[13]

Sensorization and the Internet of Things

We are creating the largest system ever in human history, like a "nervous system" that detects, sends signals and responds, generating data at unprecedented scale for analysis. A wide variety of sensors are deploying rapidly across our natural, built, production and personal environments. Our phones have sensors. City trash cans have sensors. Building lighting systems have them. Doorknobs, roads, farm fields, home devices, wearable tech, even livestock have them—many of them linked

11. Synthetic Biology, National Human Genome Research Institute, National Institutes of Health.
12. Building with Biology, http://buildingwithbiology.org/about-syn-bio.
13. Spinning Spider Silk into Startup Gold, Science, October 18, 2017.

to networks. In addition, the Internet of Things is connecting things on a scale once unimaginable. The number of connected devices could reach 46 billion by 2021.[14]

In production, the Internet of Things is weaving a complex web of machines, facilities, fleets, objects and people to sensors, networks and controls, enabling systems optimization. It has been estimated that productivity gains based on the Industrial Internet of Things could add $15 trillion to global GDP by 2030.[15] Sensors in connected vehicles stream data back to auto manufacturers to help them improve their products and services, and they are sharing it with some insurers. Sensors provide data for tending crops and could drive large improvements in crop management from square meter farming to agriculture on a regional level. Sensors and the Internet of Things are creating the platforms for smart cities, intelligent highways and traffic management, supply chain control, smart grids, food safety and security, public works management, health monitoring, unprecedented battlefield awareness and control, and more. Eventually, people may simply interact with their environment through voice, gesture, respiration or body temperature, rather than interacting physically with objects or devices directly.[16]

Big Data

We are experiencing the datafication of how humans live and what we do. In addition to the data being generated through sensors, hundreds of millions of people are generating billions of data points every minute of every day through social media, transactions, Internet searches, interaction with the health care system and other activities. The data universe is already of massive scale, estimated to be nearly doubling in size every two years,[17] and pouring into every area of society and the global economy. And we are getting the tools to use massive amounts of that data to measure and gain insight on aspects of our existence in ways that have never before been possible, see patterns we have never before been able to see, and ask questions and get answers never before contemplated.

We are most familiar with big data in business, retail, marketing and advertising, financial transactions, and even the gene data pool. But big data and data analytics are providing powerful new tools for gaining insight in a wide range of fields such as sports and entertainment, match-making, crime fighting, agriculture, transportation management, disaster management, animal migration, astronomy, and historical research. Looking across sectors of the economy and society, we see the unleashing of stunning analytic power. However, the increased reliance on data raises new and challenging questions about data ownership, data privacy and protection, international data flows and cyber security.

14. Internet of Things' Connected Devices to Triple by 2021, Reaching Over 46 Billion Units, Juniper Research, December 2016.
15. Industrial Internet, Pushing the Boundaries of Minds and Machines, Peter Evans and Marco Annunziata, GE, November 26, 2012.
16. Is this the Future of the Internet of Things?, World Economic Forum, November 27, 2015.
17. The Digital Universe of Opportunities: Rich Data and the Increasing Value of the Internet of Things, IDC, April 2014.

Big Data is a Big Deal

Rapid Research. Eighty percent of 23andMe's customers for personal genome sequencing have opted-in to participate in research. Researchers were interested in seeing if a certain gene was more prevalent in cancer patients. Tapping the 23andMe pool of genotyped people, a survey was sent to individuals who have that gene. Researchers got 10,000 responses in 12 hours and had their answer in two days.[18]

Finding the Flu. Using data from Web searches performed by millions of people, Google was able to consistently detect and report flu-like outbreaks 1–2 weeks faster than the Centers for Disease Control. In the event of a breakout or malicious release of a deadly pathogen, detecting it 1–2 weeks faster could help avoid a pandemic.

Better Clinical Outcomes. Researchers at Stanford University compared EEGs of depressed patients with a data base of more than 1,800 patients that included information about their response to specific treatments. Using this data to guide treatments led to significantly better outcomes than clinical treatment selection.

Disaster Management. As reported by the World Economic Forum, researchers obtained data on the outflow of people from Port-au-Prince after Haiti's 2010 earthquake by tracking the movement of nearly two million SIM cards in the country. They were able to determine the destination of about 600,000 people displaced from Port-au-Prince, and made this information available to government and humanitarian organizations dealing with the crisis.

Poisoned. The Old Bailey Online contains records and transcripts from 197,000 trials held at the Central Criminal Court in London from 1674–1913. Analyzing the data reveals that, in 18th and 19th century London, a drink such as coffee was the favored delivery vehicle for poisoning a person.

18. How 23andMe is Monetizing Your DNA, Fast Company, January 5, 2015

Artificial Intelligence (AI)

Computing, big data and autonomous systems are converging in the field of AI. AI could be one of the most disruptive technologies of the 21st century. Like electricity lit the world, analysts expect the broad deployment of AI, transforming how we do business, produce food, manufacture products, travel, manage finances, diagnose disease, carry out military operations and more.

Broad application of AI could lead to an intelligent society, disrupting business, societal patterns, the workforce and the global balance of power. U.S. economic and geopolitical competitors recognize this potential, for example, as envisioned by China's *Next Generation Artificial Intelligence Plan* released in 2017 (as translated):

> *The rapid development of artificial intelligence will profoundly change human society and life and change the world... AI brings new opportunities for social construction…AI is a disruptive technology with widespread influence that may cause: transformation of employment structures; impact on legal and social theories; violations of personal privacy; challenges in international relations and norms; and other problems. It will have far-reaching effects on the management of government, economic security, and social stability, as well as global governance*
>
> *AI has become the core driving force for a new round of industrial transformation, which will advance the release of the huge energy stored from the previous scientific and technological revolution and industrial transformation, and create a new powerful engine, reconstructing production, distribution, exchange, and consumption… with new demands taking shape from the macro to the micro within each domain of intelligentization; with the birth of new technologies, new products, new industries, new formats, new models; triggering significant changes in economic structure, profound changes in human modes of production, lifestyle, and thinking; and a whole leap of achieving social productivity.*

The nation that leads in AI—in its development, application and deployment—will lead a massive global transformation of the economy, society, national security and how we live our lives. It has been estimated that AI could contribute $15.7 trillion to global GDP by 2030,[19] bigger than the GDP of any country other than the United States. In another estimate, a global professional-services company analyzed 12 developed economies and estimated that AI has the potential to boost their labor productivity by up to 40 percent and double their annual economic growth rates by 2035.[20]

As intelligence migrates to machines and the virtual world, there are thorny issues related to this transition, including: trust and transparency, "explainability" (why an AI system took certain

19. Sizing the Prize: What's the Real Value of AI for Your Business and How Can You Capitalise? PriceWaterhouseCoopers, 2017.
20. Why Artificial Intelligence in the Future of Growth, Accenture, September 28, 2016.

> …the one who becomes the leader in this sphere (AI) will be the ruler of the world.
>
> **Vladimir Putin**
> President of Russia

actions and valued certain variables more than others), differing ethics and values around the world guiding AI development, risk and regulation, safety, security, engineering in the context of rapid response systems, drawing a balance between human and AI-based decisions, the risk of manipulating and deceiving users, and high-tech dependency.

Autonomous Systems

The world is on the verge of a revolution in transportation. Tech and auto companies are racing to get autonomous vehicles on the road. Fully self-driving automated vehicles could be available within the next decade, increasing safety, improving mobility and access to transportation, and decreasing the costs of goods delivery. Automated vehicles that rely on AI could be deployed in a variety of applications such as automated transit services, commercial trucking and home delivery. This revolution will have disruptive effects on infrastructure, and across numerous manufacturing and service industries such as auto manufacturing and repair, parking garages, the taxi industry, goods delivery, the fast food industry, mass transportation systems, road and highway construction, traffic management and urban planning to name a few.

Drone registration with the U.S. Federal Aviation Administration has hit one million.[21] Drones have been put into service by the U.S. military, and have brought the public dramatic images of forest fires, floods, earthquake damage and war-torn regions never before possible. Drones can be deployed in a wide variety of applications, such as shipping and delivery, disaster assistance, remote site and equipment inspection, law enforcement, search and rescue, surveying land and crops, news gathering and filming making.

The robot market is surging. It is estimated that about 2 million industrial robots are in operation worldwide, and expected to grow to 3 million by 2020.[22] Global sales of industrial robots reached a high of 387,000 units in 2017, an increase of 31 percent over the previous year, and continuing a five-year growth trend.[23] The use of service robots is increasing in areas ranging from logistics and medical applications, to lawn mowing and window cleaning. Robotic exoskeletons are enabling paralyzed people to walk again.

21. FAA Drone Registry Tops One Million, January 10, 2018, transportation.gov.
22. Robots Double Worldwide by 2020, International Federation of Robotics, May 30, 2018.
23. Revised Market Presentation CEO Roundtable 2018, International Federation of Robotics, June 20, 2018.

Robots and autonomous systems are likely to become commonplace, working in homes and offices, assisting in hospitals and classrooms, helping run farms and mines, caring for the elderly and delivering groceries. Autonomous systems will operate across factories, smart cities and infrastructure. These systems will interface and team with humans, enable our daily lives and change the patterns of society.

Nanotechnology

At the nano-scale, matter can exhibit unique physical, chemical and biological properties that are useful and provide a basis for innovations across numerous fields of application such as medicine, environmental monitoring and clean-up, drinking water, electronics, energy, infrastructure, transportation, a wide range of films and coatings, food safety, even clothing. It could affect all materials, and enable powerful new capabilities, entirely new properties and products with functionality that otherwise would be impossible.

Nanotechnology: Large Potential for Innovation in a Small World

Source: nano.gov

Water repellent coatings and surfaces

Stain proof clothing

Antimicrobial surfaces

Invisibility cloak

Lab-on-a-chip

Drug delivery directly to cancer cells

Nanoribbons to help repair spinal cord injuries

Food safety monitoring

Nanocrystals that protect plants from frost

Sensing machines that operate inside living systems

Ultra-sensitive chem/bio detectors

Film membranes for water desalination

Low cost water purification

Flexible, bendable, foldable, rollable electronics

Self-healing, mark and scuff-resistant paint

Self-cleaning windows

Scratch resistant glass

Artificial muscle and cartilage

Paper-thin wearable loudspeaker

Clothing that harvests energy through movement

Sensorization/Internet of Things/ Connectivity

24/7 patient monitoring/data collection
Self-health monitoring/data collection
Real-time symptom alerts/treatment triggers
Medication management/compliance
Broad/mobile access to health care information
Persistent scientific observation/data collection
Health industry supply chain optimization
Equipment maintenance management
Medical asset tracking

Big Data

Person datafication for tailored healthcare
Early detection of disease outbreak
Epidemic response
Clinical research
Drug discovery
Clinical treatment selection
Healthcare activity/cost data analysis
Health economics
Source ID (food poisoning/contagious disease)
Hospital staffing management
Regional health care system planning
Insurance claim fraud prevention

Biotech

Correct genes th
Redesign organisms
Information for targeted
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Artificial Intelligence
Disease diagnostics
Medical image analysis
Intelligent assistant for elderly/cognitively impaired
Predict personalized health outcomes
Drug discovery
Health/patient condition monitoring
Treatment selection
Virtual nursing assistants
Patient screening/triage
Clinical decision making
Virtual administrative assistant

Autonomous Systems
Robotic surgery
Robotic caregivers for patients/elderly
Micro-robotics for in-body treatment/targeted drug delivery
Treatment of patients with highly infectious diseases
Physical therapy
Assistance in daily tasks for physically/cognitive impairment
Medication dispensing
Prosthesis/limb aids/exoskeletons
Material/patient transport/lifting
Patient simulators
Dealing with hazardous waste/substances
Laboratory automation

On the Eve of Disruption

The Future of Production, Sustainable Consumption and Work

The revolutionary technologies that are emerging have the potential to disrupt the patterns of society and living, U.S. jobs, labor markets, communities, and the ways in which work and human activities are conducted.

Nature of Technological Disruption

The reorganization of the economy and society around powerful technologies is a dynamic process undertaken by businesses, government and people. It is inherently disruptive, both creating and destroying businesses, markets and jobs. This dynamic process is essential to leveraging new technology to generate the greatest benefits in terms of jobs, economic growth, productivity and wealth.

There are many potential dimensions to these disruptions, and they can occur at every level of the economy. They can create new industries and make others obsolete. They can disrupt industrial and consumer markets by enabling new product and service offerings, even coming from industries that had previously never served a particular market. As the economy reorganizes around new technologies, new firms are born and others may grow, while other firms decline or shut their doors. Labor markets can roil as technology replaces workers, makes occupations or skills obsolete, or creates new types of jobs and demands for new skills. Countries and communities can face disruption as industries fade or new industries rise, and as new technologies alter the ways in which humans carry out activities across society.

Imagine you had a device that combined a telephone, a TV, a camcorder, and a personal computer. No matter where you went or what time it was, your child could see you and talk to you, you could watch a replay of your team's last game, you could browse the latest additions to the library, or you could find the best prices in town on groceries, furniture, clothes—whatever you needed.

Vision from 1993 Clinton Administration Policy:

The National Information Infrastructure: Agenda for Action

The cycle of disruption and reorganization is dramatically illustrated by the digital revolution. As the digital revolution scaled-up over a period of about two decades, a whirlwind of creative-destruction reshaped the landscape. Firms were born and firms died. Older firms adopted new business strategies and models. Firms that did not exist in 1993—Google, Facebook and Amazon—now exert tremendous market, political and social power. New service industries emerged, while other industries—

music and film, telecommunications, broadcasting, publishing and distribution—were disrupted. New ways of doing business swept the global economic landscape. New occupations emerged, and new skills were required of many. Consumers have been endowed with new power in the marketplace, and society has adopted new ways of communicating and socializing. Out of its turbulence has come a profound transformation of the economy, business and society.

Work, the Workplace and the Workforce

A disruptive technology can drive a reordering of production at every level of the economy—from the desktop to the workplace, to the labor market, to the mix of industries in a community or country—creating new opportunities but also hardships for some workers. For example, AI is expected to have a major impact:

- At the **task and job level**. AI is likely to affect portions of almost all jobs, change the tasks performed, and the way work is organized, decisions made and problems solved.
- At the **organizational level**. AI could change the size and mix of human capital and skills needed in the organization.
- At the **industry level**. AI and autonomous systems will create new jobs in new industries, drive expansion of employment in some incumbent industries and losses in others.
- At the **occupational and labor market levels**. AI and autonomous systems may create new or eliminate existing occupations, change what occupations are in demand and change the market value of skills.

Examples of How Technology Can Affect Jobs and Workers

Task/Job Level	
Change skills needed on the job	• Machinists who once worked with manual lathes and drills need new skills to operate CNC machine tools. • More electric/hybrid vehicles on the road means automotive service technicians/mechanics must be able to work on high-voltage electrical systems, lithium-ion batteries, and electric generators.
Change the way work is organized	• 20th century workplace characterized by hierarchy and work "place;" today, workplace characterized by networks; networks and mobile computing decoupling work from place; some workers have greater autonomy. • Customer on-line travel and ticket booking reducing demand for reservation and ticket agents. • Use of digitized self-service checkout lanes in groceries mean fewer hand packers and packagers needed to bag groceries.
Change tasks performed	• Instead of manual typesetting, printers use digital publishing/desk top printing. • Manual tasks in production have been reduced by automation; workers have become monitors of automated production lines. • Scientists using more computational tools in research, substituting human effort with computational techniques such as data analytics, and simulation and modeling.
Organizational Level	
Make workers more productive, so fewer workers are needed or jobs eliminated	• Advancements in surveying technology have increased the amount of work a surveyor or surveying technician can do, reducing the demand for surveying technicians. • Demand for insurance underwriters expected to fall; underwriting software helps workers process insurance applications quickly.
Change mix of human capital and skills needed in the organization	• Industrial robots reduce need or eliminate jobs for assembly workers, but increase need for programmers and robot maintainers. • Use of electronic filing/data bases reduces need for file clerks, but increases need for data base administrators.

Examples of How Technology Can Affect Jobs and Workers	
Industry Level	
Drive expansion in an existing industry's employment	• Fracking and horizontal drilling technology significantly raising oil and natural gas production, increasing employment in U.S. oil and gas industry by more than 40 percent from 2007-2015.
Create new industries with growing employment; drive declines and employment losses in other industries	• Personal computer drove employment growth in computer systems design and software publishing, but reduced/eliminated employment in computer mainframe industry. • Increased use of Internet, e-readers, and tablets expected to cause job losses in newspaper, periodical, book publishing industry. • Expanded use of e-mail, on-line bill pay, automatic mail sorting forecast to contribute to declines in Postal Service employment.
Occupational Level	
Create new or eliminate existing occupations	• Personal computing eliminated jobs for computer operators and data-entry keyers; new occupations established such as network administrator and help desk personnel. • Robots and computers are replacing welders in manufacturing. • Low cost gene sequencing creating genetic counselor occupation.
Labor Market Level	
Change what skills/occupations in demand	• Personal computing, networking, Internet expansion have driven major growth in demand for IT professionals such as software engineers, computer systems analysts, and network administrators. • The increasing use of big data is driving increased demand for mathematicians and statisticians.
Change supply of skills/ occupations in the labor market	• Rapid employment growth and high demand for IT workers raised wages, motivating students to study computer science in college, and others to participate in wide range of IT training increasing skills availability in the market place.
Change labor market value of skills	• IT workers with "hot" or the latest skills are in high demand and command wage premium in the labor market.

In the coming world of collaboration between humans, robots and intelligent systems, and as we integrate virtual and augmented reality into the enterprise, we could fundamentally reimagine how work gets done. As cognitive science unlocks the mysteries of the mind and how our brains give rise to our thoughts, perceptions, reasoning, actions, how we think and learn, we will gain new insight on the creative process, creativity and how to nurture it, and how to better analyze, solve problems, adapt to new situations and make decisions. New knowledge about cognition will be applied to improve how we work together, manage teams, design organizations and interact with customers. And this new knowledge will be embedded in our machines and human-machine interfaces.

Automation—robots, machines, devices, sensors and software—is increasingly capable of doing routine tasks that have made up jobs for millions of Americans. For example, Internet systems provide customers with account information and payment processing. Tax preparation software carries out work once performed by accountants. Financial institutions use software to assess credit risk. And sensors and imaging technologies perform security functions. The price of automation has fallen significantly in the past few decades, both in absolute terms and relative to the cost of labor.[24] As the cost of labor rises, and the cost of automation declines, it becomes more attractive to automate work and eliminate some jobs.

24. Job Polarization Leaves Middle-Skilled Workers Out in the Cold, Maria E. Canon and Elise Marifian, The Regional Economist, Federal Reserve Bank of St. Louis, January 2013.

Automation has eliminated many middle-skill jobs that underpinned 20th century middle-class life. For example, during the 20th century, manufacturing was a source of well-paying low- and middle-skill jobs, supporting a middle-class lifestyle for millions of Americans. But about five million jobs in manufacturing were lost from 2001-2010,[25] (although we have gained back more than a million manufacturing jobs in recent years). Automation has eliminated many routine assembly jobs; fewer than 39 percent of workers in U.S. manufacturing establishments are now directly engaged in production.[26] And many of the jobs that remain in manufacturing require greater education and skills.

There is little consensus on how many jobs could be automated in the years ahead. One review showed dramatically different predictions about jobs that automation could create and destroy, for example, with estimates for job losses in the United States ranging from 3.4 million by 2025 to 80 million by 2035.[27] But the studies also indicated that millions of new jobs would be created.

It may not be a good time for those whose skills limit them to routine work, as smart systems, sensors and software are increasingly capable of doing that work. Many Americans are worried; in a recent survey, 72 percent of U.S. adults were worried about a future in which robots and computers are capable of doing jobs done by humans.[28]

25. U.S. Bureau of Labor Statistics.
26. U.S. Manufacturing in International Perspective, Congressional Research Service, March 17, 2015.
27. Every Study We Could Find on What Automation Will Do to Jobs, in One Chart, MIT Technology Review, January 25, 2018.
28. 6 Key Findings on How Americans See the Rise of Automation, Pew Research Center, October 4, 2017.

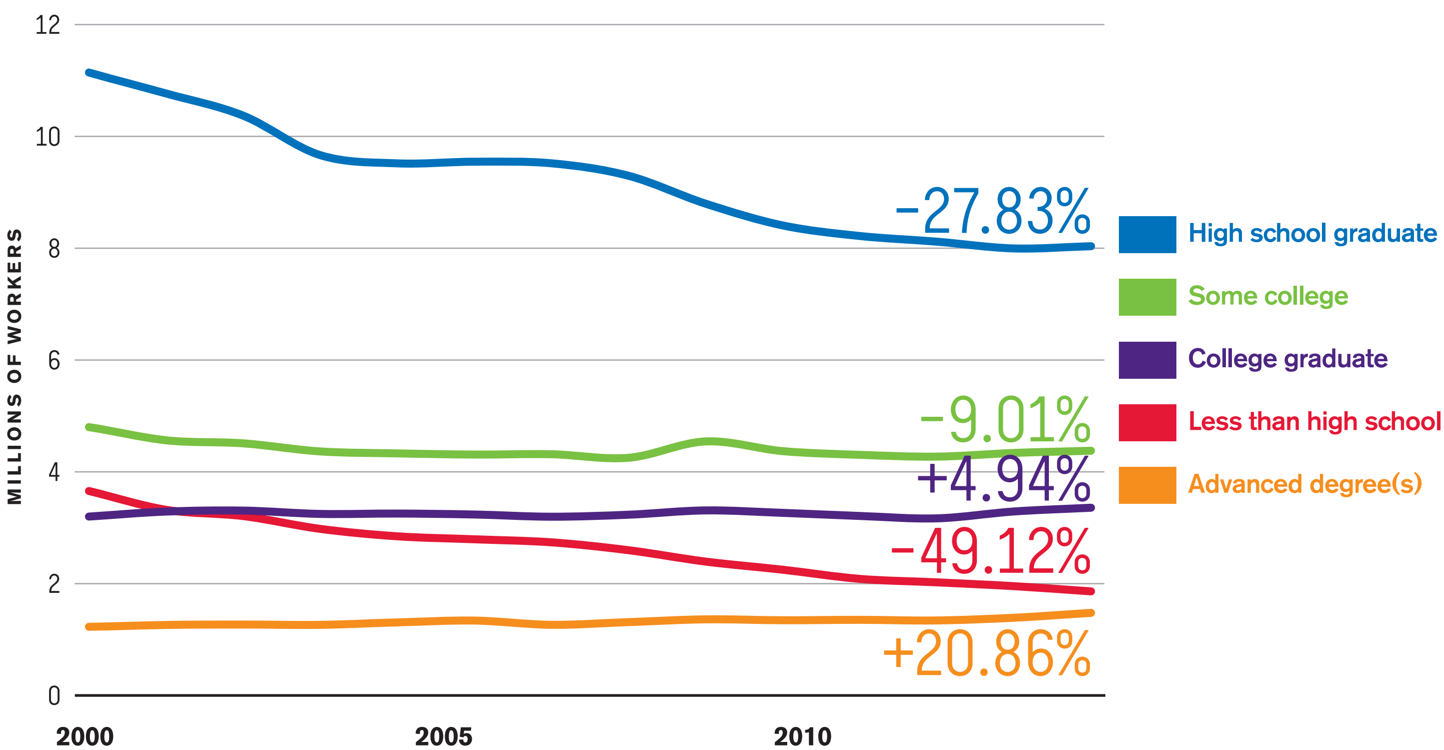
In contrast, the labor market is rewarding the well-educated workers who can perform non-routine work and complex tasks (Figure 6). Higher-skilled workers are not only at a premium when new technologies are introduced, because they are better able to use them, they are also better prepared to move to new industries, new jobs, new occupations or new skills when displaced by technological, labor market or market disruptions.

From technology to trade skills, there is no issue on which Council members are more united than in their desire for progress on building a talented, diverse workforce. As technology and a retiring baby boomer generation contribute to reshaping the jobs landscape, leaders must work at all levels, in the private and public sectors, to prepare Americans for the changes to come.

The Council continues to recommend several steps to address talent shortfalls, urging both government policy action and partnerships between government,

Figure 6. Manufacturing Jobs by Educational Achievement

Source: Steven Ruggles, J. Trent Alexander, Katie Genadek, Ronald Goeken, Matthew B. Schroeder, and Matthew Sobek. Integrated Public Use Microdata Series: Version 5.0 [Machine-readable database]. Minneapolis: University of Minnesota, 2010.



industry, academia and labor. America needs to take many steps, including: growing the number and diversity of its STEM-educated workforce, establishing greater opportunities for experiential learning (e.g. co-ops and apprenticeships), and reforming rules to retain more skilled immigrants. Other critical steps include encouraging greater lifelong learning opportunities, and re-establishing hands-on training classes in K-12 that build a base for skilled trades.

Communities

Technological disruptions can test the resilience of communities as they face changes in their economic fortunes or the loss of jobs. To this day, you can drive across America and see places and people still left behind by the transformations that occurred in agriculture and manufacturing as long as a century ago—rural poverty, tiny depopulated towns with boarded up shop fronts, decaying housing stock, old brick factories of a by-gone era with broken windows, the rail spurs that once brought materials in and took products out choked with weeds.

New technologies can even create problems when they drive rapid increases in jobs and economic activity, as we see places such as Silicon Valley and Seattle, Washington struggling with rising housing costs as their populations have grown with the IT revolution.

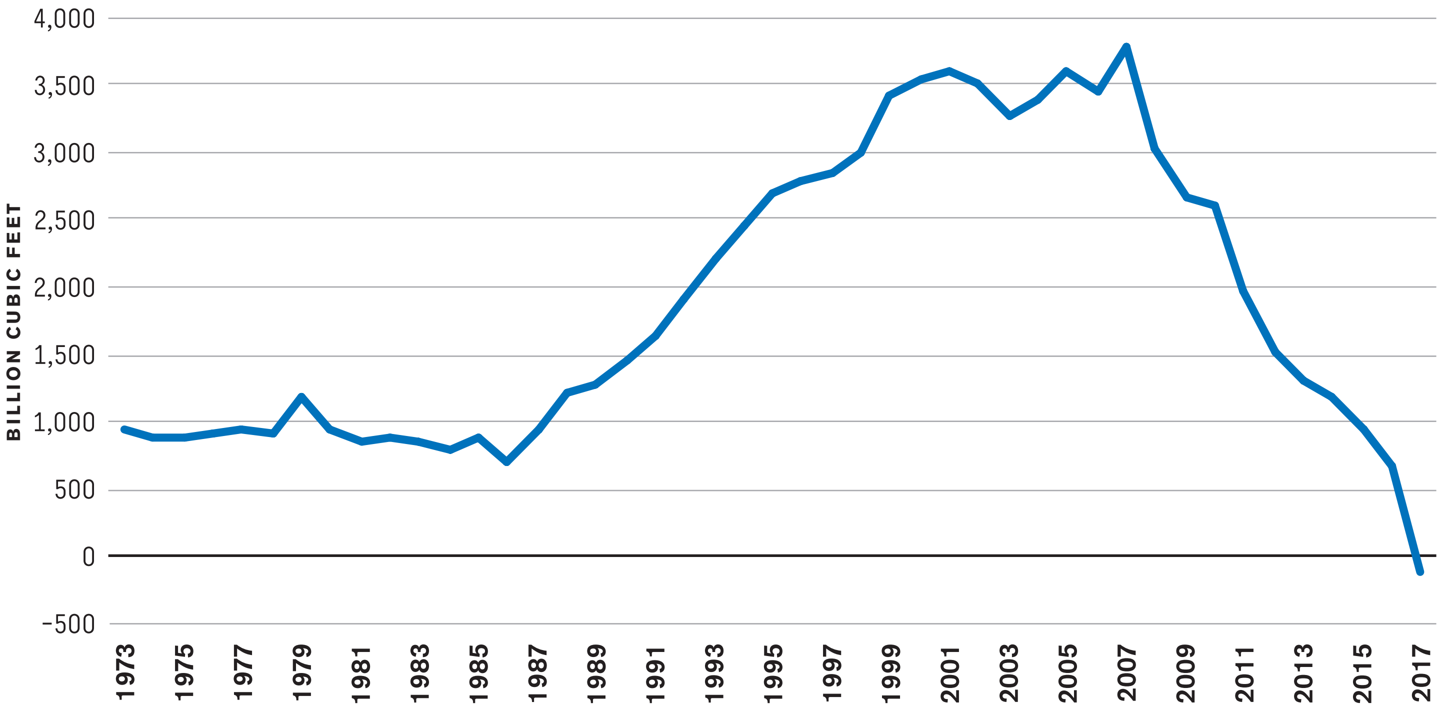
Other communities have faced disruption from advancements in hydraulic fracturing, horizontal drilling and seismic imaging technologies, which have converged to deliver a treasure trove of oil and natural gas from U.S. shale formations, dramatically reversing the U.S. position in energy (Figure 7). For example, these technologies drove increases in total dry natural gas production from 19.3 trillion cubic feet (Tft^3) in 2007 to 26.5 Tft^3 in 2016, an overall increase of 7.2 Tft^3. And, during the same period, U.S. shale gas production increased by 14.5 Tft^3, from 1.3 Tft^3 to 15.8 Tft^3.

Shale oil and gas is driving economic and social change in the communities where it is booming. Much of the growth in U.S. natural gas production has occurred in Ohio, Pennsylvania and West Virginia. Economic benefits are occurring all across the value chain, and many communities are seeing new economic opportunity and jobs. From 2007-2016, the number of employees in the region employed in shale industries increased by 80 percent, while the number of shale establishments increased by 62 percent.[29] In the boomtowns, many businesses see new customers. Landowners enjoy royalty payments, while governments get extra tax revenues. But those same boom communities and their governments face new challenges: increased demand for housing, schools and public services; the social problems of a transient workforce; and more traffic, noise and pressure on the local and regional health care system.

29. Shale Gas Production and Labor Market Trends in the U.S. Marcellus-Utica Region Over the Last Decade, Monthly Labor Review, August 2018.

Figure 7. The United States Moves from a Net Importer to Net Exporter of Natural Gas

Source: U.S. Department of Energy, Energy Information Administration. U.S. Natural Gas Net Imports. Accessed November 14, 2018. https://www.eia.gov/dnav/ng/hist/n9180us1A.htm.



Society

A few technologies have had major disruptive effects across society. For example, mass production of relatively low-cost automobiles transformed the United States and U.S. society. People moved from cities to sprawling suburbs that grew with new businesses and other amenities supporting suburbanites, changing the geographic face of the country. A vast system of highways and roads not only took Americans on commutes to work and distant driving vacations, but also boosted U.S. commerce tremendously because goods could be moved quickly and efficiently.

Facebook and other Internet platforms have changed the way many individuals engage in personal relationships, consume news, and research information on an ever-widening range of topics from recipes and plumbing problems, to traffic jams and symptoms of illness. But social media has been used to spread propaganda and misinformation, organize disruptive events and launch attempts to influence elections. It has been used as a vehicle for harassment and the means for widespread cybercrime. And questions have been raised about bias in reporting news and in Internet search results. Widespread collection of personal data and "digital exhaust" generated from the use of digital tools and media, and the use of data analytics, automated systems and algorithms for decision-making and authentication raise new questions about cyber security, data privacy and protection, data ownership and cross-border data flows.

Looking ahead, intelligent systems could help the elderly stay in their homes, and help those in poor health. Intelligent cars will save lives, create new mobility for the elderly and disabled, and increase traffic throughput on existing roads. However, the public may be leery about these benefits. For example, in a Pew Survey, 65 percent thought it would be a change for the worse if lifelike robots became the primary caregivers for the elderly and people in poor health, while 50 percent would not ride in a driverless vehicle.[30] There are also concerns about cyber security and vulnerabilities in autonomous systems, and ensuring that on-board data and sensors are not compromised.

Intelligent systems can offer unlimited attention and patience in building relationships, teaching and listening to problems. But, just like click bait and video games stimulate reward centers in the brain, AI could be programmed to do that too, creating new forms of high-tech human dependency. There is also the potential to spread false or dangerous misinformation through corrupt chatbots or expert systems.

Gene-editing is one of the most powerful technologies ever discovered by humankind. However, these powerful capabilities present ethical, social and regulatory challenges, and their misuse could pose a significant threat to public health and safety, the environment and national security. There is also concern that access to gene-editing for disease mitigation and life extension will initially be available in only a few rich countries, creating new divisive political debate over access.

Advancements in materials, biology, pharmacology, digital technology, and neuro- and cognitive science could lead to human augmentation—such as significant enhancement of eyesight or hearing, and powerful exoskeletons that increase human strength. Neuro-enhancements could provide extended concentration, superior memory recall and speed of thought, accelerated learning and better decision-making. A recent survey suggests that one quarter of Americans would be willing to get a brain implant to improve their memory or mental capacity.[31] Human augmentation technologies could reshape the economic and military advantages between nations, and exacerbate divisions between haves and have nots.

The fast pace of development could challenge governments and the scientific community in efforts to develop regulatory regimes and norms for responsible use of these powerful technologies. Ethical principles vary across countries, regions, cities and individuals, shaped by experiences, identities, and the roles of public institutions and private companies in different countries. Whose cultural norms, value systems and ethics will guide the limits in using these powerful technologies?

30. U.S. Views of Technology and the Future. Pew Research Center, April 17, 2014.

31. U.S. Views of Technology and the Future. Pew Research Center, April 17, 2014.

Gearing-up: Optimizing the Environment for Innovation Systems

Since the early 2000s, new models of innovation have emerged, and others have matured in response to the transformation of the global competitive landscape that began in the 1980s (Figure 8). Multiple technology revolutions and their convergence, and the nature of global challenges require models of innovation built on internal resources, external collaboration and a larger, more diverse innovation skill set. For example, in a recent survey of U.S. manufacturing firms, of those firms that had innovated, 49 percent reported that the invention underlying their most important new product had originated from an outside source.[32] These models of innovation have expanded the scope of participants in the innovation ecosystem, and ways in which companies, innovators and entrepreneurs pursue innovation.

Figure 8. New Models and Major Changes Disrupting Systems of Innovation

Many businesses have shifted their R&D away from exploratory research toward nearer-term research that supports business units. Today, technology breakthroughs are just as likely to come from universities, national laboratories and small start-ups, causing businesses to look externally as well as internally for sources of invention and innovation.

The democratization of innovation through self-organization (maker spaces, desk-top manufacturing, DIY biotech), crowd funding, citizen science and open source digital platforms—including platforms that connect problem-solvers with solution seekers—has expanded the universe of innovators.

Regional, state and local communities increasingly see innovation as a major source of economic growth and job creation, and expect institutions of higher education to contribute to economic growth. These communities are investing in technology and innovation initiatives (proof-of-concept centers, technology demonstration centers, innovation hubs, academic-industry partnerships, etc.) as major elements of their economic development strategies.

Big data, data analytics, modeling and simulation are providing powerful new tools for the researcher and innovator, allowing a scale of research, discovery and experimentation impossible in the laboratory. These tools are also increasingly used to explore and select innovation pathways with the highest likelihood of success, while avoiding unsuccessful and expensive trials that do not bear fruit.

Innovation is de-linking from institutions. It is now possible for someone to imagine, develop and scale a disruptive technology independent of traditional institutions of innovation.

32. The Acquisition and Commercialization of Invention in American Manufacturing: Incident and Impact, by Ashish Arora, Wesley Cohen and John Walsh, NBER Working Paper, National Bureau of Economic Research, 2016.

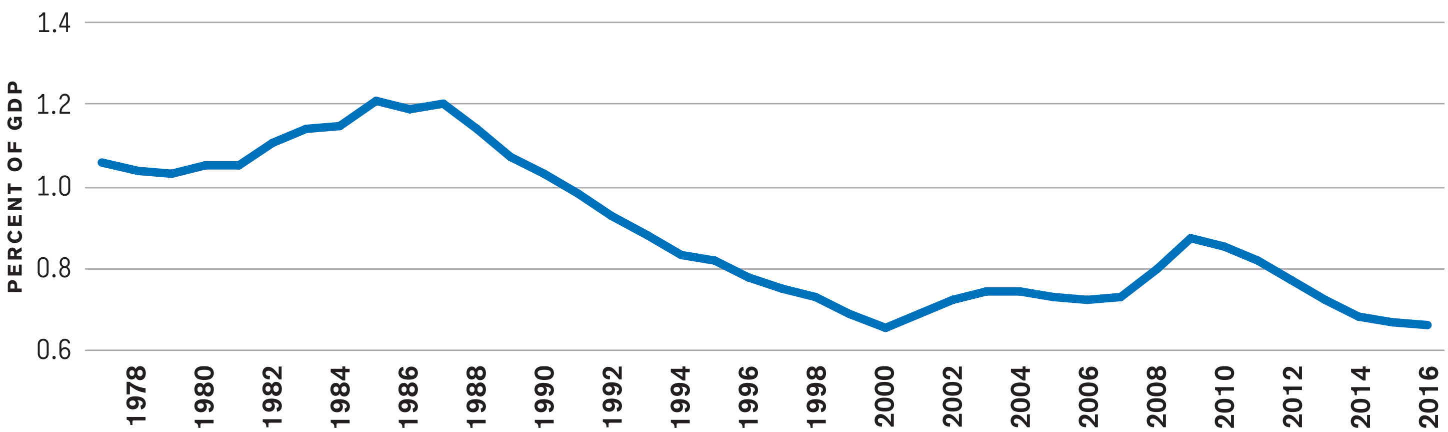
As companies have moved away from exploratory research toward nearer-term applied research and technology development that supports business units, foundational technology breakthroughs increasingly come from universities, national laboratories and small start-up companies that are disproportionately supported by public R&D investments. While the public role in the innovation ecosystem has increased in importance, U.S. public investment has not kept pace (Figure 9). This government investment plays a key role as seed corn for future applied research and technology development, and for training the next generation of scientists and engineers. However, with increasing democratization of innovation, a growing pool of innovators and problems solvers are largely disconnected from the research, development and training institutions this public investment supports.

There are many factors that affect a county's ability to innovate and compete. This includes levels of investment in R&D, the availability of capital including venture capital to fuel start-ups and innovation at critical stages, the availability of talent, the environment for entrepreneurship, and the general business environment including taxes and the level of business regulation. These elements are different in countries around the world, and can play a significant role in a country's competitiveness and capacity for innovation.

U.S. competitors around the world seek to build and strengthen knowledge and technology-based economies as the basis for advancing productivity, job creation, raising standards of living and, in some cases, advancing geopolitical goals. As a result, many deploy policies and programs to harness science, technology and innovation, and to create a business environment to achieve this impact. These countries are instituting their own distinctive innovation ecosystems, which may not be compatible or friendly with the U.S. innovation system.

For example, in the United States, the private sector dominates R&D spending, and the Federal government spends significant funds on defense R&D and basic research. Other countries' R&D is dominated by government funding. The United States is home to many of the world's top research universities and a distinctive set of crown jewel

Figure 9. Federal Government Funding of R&D as Percent of Gross Domestic Product
Source: National Science Foundation



national laboratories, while other nations are working to strengthen their university-based research and industry engagement with research institutions. The United States is known for its strong policies of technology transfer and intellectual property ownership of technologies developed with government funding. Other nations' science, technology and innovation efforts are strongly guided by national strategic plans, and many have high-level ministries devoted to stimulating technology and innovation. Many countries have national research programs or projects that target emerging technologies and fields. The strength of the start-up and entrepreneurial culture varies by country. In the United States, state and regional governments play a significant role, with a wide variety of programs designed to stimulate technology-based economic growth, such as accelerators, incubators for start-up firms and seed funds. Other countries may deploy protectionist policies and illicit means to advance their technology positioning.

While not comprehensive, Figure 10 illustrates some of the diverse strategies, policies, programs and spending different countries implement, creating distinctive innovation ecosystems.

Figure 10. Illustrative Innovation Ecosystem Characteristics/Practices

Sources: OECD Science, Technology and Innovation Outlook 2016; Science and Engineering Indicators 2018, National Science Foundation; 2018 Global R&D Funding Forecast, R&D Magazine, Winter 2018; national S&T plans.

United States

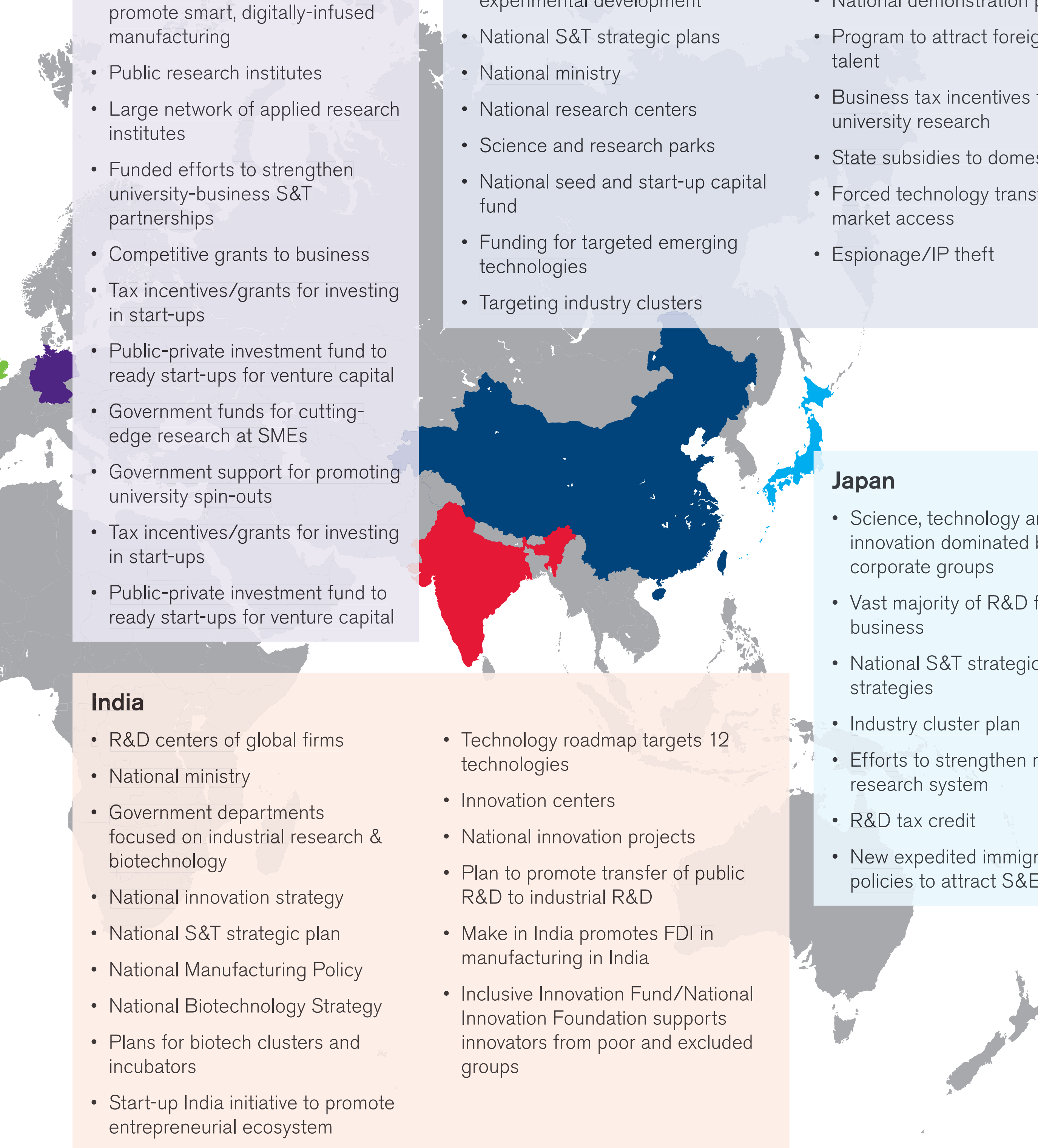
- No. 1 global R&D spender
- No. 1 global spender on basic research
- No. 1 global spender on applied research
- Large expenditure on military R&D
- Business dominates R&D spending
- National research programs
- Unique national laboratory system
- Top research universities
- R&D tax credit
- Small Business Innovation Research program to drive innovation for government missions
- Manufacturing Innovation Institutes
- Science and research parks
- Start-up culture
- Strong venture capital system
- State/regional innovation programs

United Kingdom

- Top research universities
- National plan for science and innovation
- Government department for business innovation
- Two national science and innovation campuses with business enterprise zones
- National Research Councils
- R&D tax credit
- Global Challenges Research Fund targets areas where multidisciplinary research is required
- Tax break for profits from products derived from U.K./EU patents
- Small Business Research Initiative to drive innovation through public procurement
- Networks, clusters, centers to bring university research to industry

Brazil

- National science and technology programs
- Targeting key sectors
- Government-funded competitive grants for R&D in key sectors
- Government-funded technology parks
- Government grants for start-ups
- Tax incentives for purchase of research equipment
- Government credit, grants, equity financing for company innovation



Germany

- R&D investment civilian focused
- National research ministry
- National high-tech strategy
- Industry 4.0 initiative to promote smart, digitally-infused manufacturing
- Public research institutes
- Large network of applied research institutes
- Funded efforts to strengthen university-business S&T partnerships
- Competitive grants to business
- Tax incentives/grants for investing in start-ups
- Public-private investment fund to ready start-ups for venture capital
- Government funds for cutting-edge research at SMEs
- Government support for promoting university spin-outs
- Tax incentives/grants for investing in start-ups
- Public-private investment fund to ready start-ups for venture capital

China

- No. 2 global R&D spender
- No. 1 global spender on experimental development
- National S&T strategic plans
- National ministry
- National research centers
- Science and research parks
- National seed and start-up capital fund
- Funding for targeted emerging technologies
- Targeting industry clusters
- National strategy to foster entrepreneurship
- National demonstration projects
- Program to attract foreign S&T talent
- Business tax incentives for university research
- State subsidies to domestic firms
- Forced technology transfer for market access
- Espionage/IP theft

Japan

- Science, technology and innovation dominated by large corporate groups
- Vast majority of R&D funded by business
- National S&T strategic plan and strategies
- Industry cluster plan
- Efforts to strengthen national research system
- R&D tax credit
- New expedited immigration policies to attract S&Es

India

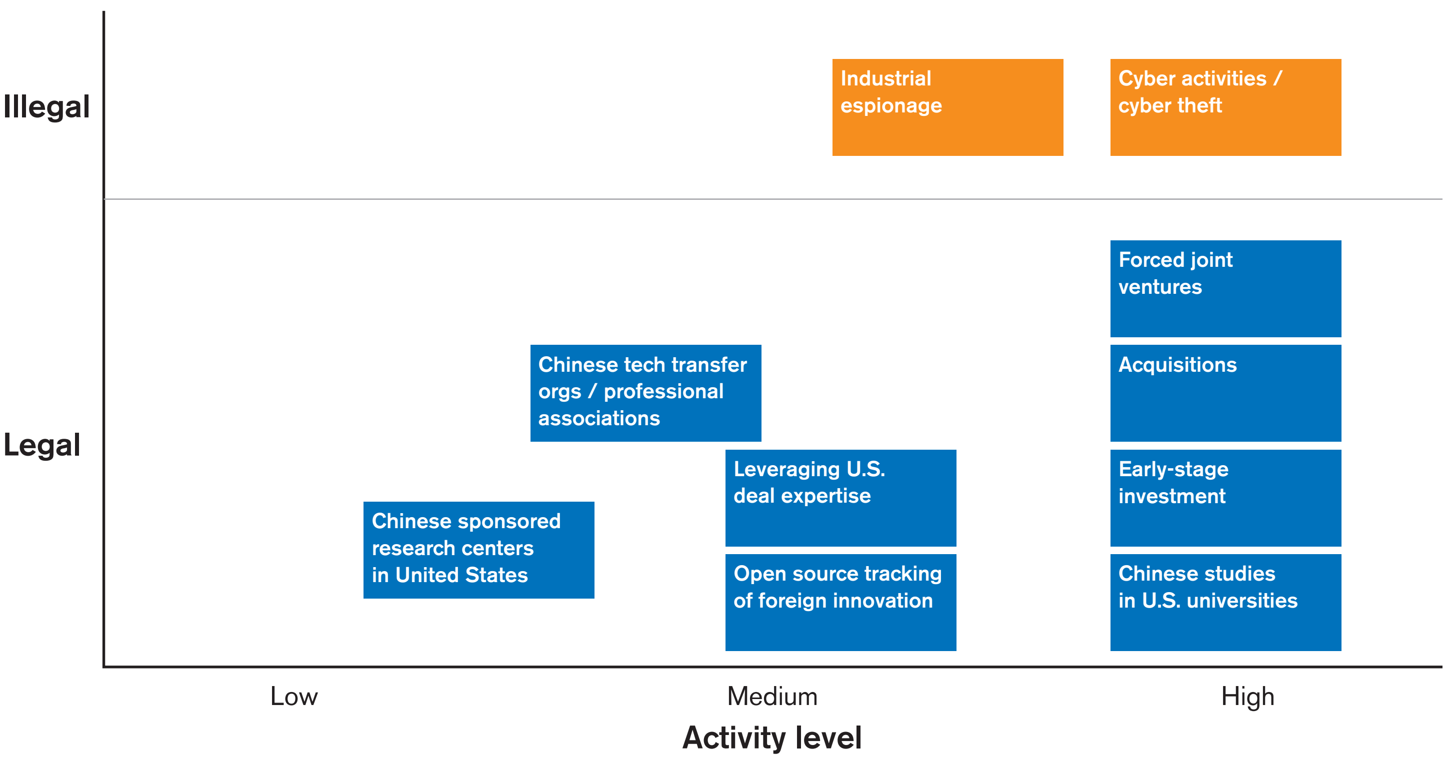
- R&D centers of global firms
- National ministry
- Government departments focused on industrial research & biotechnology
- National innovation strategy
- National S&T strategic plan
- National Manufacturing Policy
- National Biotechnology Strategy
- Plans for biotech clusters and incubators
- Start-up India initiative to promote entrepreneurial ecosystem
- Technology roadmap targets 12 technologies
- Innovation centers
- National innovation projects
- Plan to promote transfer of public R&D to industrial R&D
- Make in India promotes FDI in manufacturing in India
- Inclusive Innovation Fund/National Innovation Foundation supports innovators from poor and excluded groups

China: A Rising Technological Superpower

In declaration, data and deed, it is obvious that China has set its sights on world technology leadership, presenting a growing strategic competitive challenge to the United States (Figure 11). China has developed a leading global economy faster than any country in modern history. The timescale of its growth—from 10 percent of the U.S. economy (GDP) in the 1970s, to the second largest global economy in 50 years—positioned China to achieve in less than half a century what took the United States about a century to achieve.[33]

China is rapidly strengthening in science and technology. China's investment in R&D has more than doubled since 2010, reaching $451 billion in 2016, second only to the U.S. investment, and set to outpace the United States by the end of this decade. China has overtaken the United States in science and engineering publications. China has an 18.6 percent world share, while the United States has a 17.8 percent share.[34] China has posted double-digit growth rates in international patent filings in every year since 2003, and now lags only the United States in patents filed.[35]

Figure 11. Vehicles for Chinese Technology Transfer from the United States
Source: China's Technology Transfer Strategy: How Chinese Investments in Emerging Technology Enable A Strategic Competitor to Access the Crown Jewels of U.S. Innovation, Defense Innovation Unit Experimental, January 2018.



33. China's Technology Transfer Strategy: How Chinese Investments in Emerging Technology Enable A Strategic Competitor to Access the Crown Jewels of U.S. Innovation, Defense Innovation Unit Experimental, January 2018.

34. Science and Engineering Indicators 2018, National Science Foundation.

35. Patent Cooperation Treaty Yearly Review 2018, World Intellectual Property Organization, 2018.

China's global venture investments are growing rapidly. From 2013-2017, $363 billion in China-led manufacturing and acquisition deals were completed in high technology.[36] Chinese investment into early-stage U.S. technology companies is also growing, peaking at 16 percent of all venture deals in 2015. China's total investment in U.S. technology ventures totaled $35 billion over 2006-2016. The technologies in which China is investing are technologies that will be foundational to future innovation: AI, autonomous vehicles, augmented/virtual reality, robotics and gene-editing.[37] Of the $154 billion in global venture financing in 2017, 40 percent came from Asia (with China leading), up from less than 5 percent a decade ago; American investors' share was 44 percent.[38]

The **Made in China 2025** initiative, announced in 2015, seeks to transform China from a manufacturing giant into a world manufacturing power by 2049, while it set a target to become one of the most innovative countries by 2020 and a leading innovator by 2030.[39] Made in China targets advanced IT, advanced machine tools, robotics, aerospace technology, maritime equipment, new energy vehicles, biomedicine and advanced medical equipment.[40]

36. Exponential Technologies in Manufacturing, Deloitte, Singularity University and Council on Competitiveness, 2018.
37. China's Technology Transfer Strategy: How Chinese Investments in Emerging Technology Enable A Strategic Competitor to Access the Crown Jewels of U.S. Innovation, Defense Innovation Unit Experimental, January 2018.
38. Silicon Valley Powered American Tech Dominance—Now it has a Challenger, Wall Street Journal, April 12, 2018.
39. China's Technology Transfer Strategy: How Chinese Investments in Emerging Technology Enable A Strategic Competitor to Access the Crown Jewels of U.S. Innovation, Defense Innovation Unit Experimental, January 2018.
40. Made in China 2025: Global Ambitions Built on Local Protections, U.S. Chamber of Commerce, 2017.

MIC 2025 aims to leverage the power of the state to alter competitive dynamics in global markets in industries core to economic competitiveness.

Made in China 2025: Global Ambitions Built on Local Protections
U.S. Chamber of Commerce, 2017

China is targeting development of the entire semiconductor ecosystem, including spending of more than $150 billion over 10 years for investments and acquisitions.[41] China made a major move in life sciences research when its company BGI purchased 128 gene sequencers, half the global capacity for gene sequencing at that time. Today, China accounts for 30 percent of the world's sequencing capacity.[42]

China's **13th Five-Year Plan of 2016–2020 Internet Plus** focuses on raising the country into a leading position and deployer in big data, AI, smart hardware, displays, advanced sensors, wearable

41. Made in China 2025: Global Ambitions Built on Local Protections, U.S. Chamber of Commerce, 2017.
42. 2018 Global R&D Funding Forecast, R&D Magazine, Winter 2018.

devices and mobile communications. China has also launched 16 Manhattan Project-style projects in areas such as core electronics, broadband, plant genetics, drug development, aircraft, spaceflight, quantum communications, smart manufacturing, information networks, deep space and deep-sea exploration, and neuroscience.[43]

These efforts to cultivate indigenous technological innovation are backed by commitments for hundreds of billions of dollars in investment.

China's quest for world leadership in AI illustrates its strategic practices. China's national plan—*New Generation of Artificial Intelligence Development Plan*—is breathtaking in its scope and ambition, a blueprint for constructing an AI innovation ecosystem that they believe will make China the world's AI leader by 2030. They have laid out a vision for the deployment of AI in the construct of society, with plans to invest billions, believing that the nation the leads in AI will shape a global transformation of the economy, society, human activity and national security.

According to the national plan, they are focused on specific AI technology development capabilities, and applying a portfolio of tools to acquire and build them (Figure 12).

Most striking, they have laid out a vision for the deployment of AI in robots, vehicles, aircraft, ships, rail, interface terminals of all sorts, manufacturing, agriculture, logistics, finance, commerce, household goods, education, medical care, health and elder care, government, courts, cities, transportation systems, public safety and infrastructure—in short, in the construct of society.

They are spending and attracting billions. For example, the Chinese City of Tiajin announced a $16 billion AI fund.[44] Beijing plans to build a $2 billion AI development park.[45] Between 2010-2017, Chinese investors participated in 81 AI financings, contributing to the roughly $1.3 billion raised.[46] In 2017, 48 percent of equity funding to AI start-ups went to Chinese start-ups, up from just 11.3 percent in 2016—the first time these AI venture investments in China outpaced those in the United States.[47]

Data is the lifeblood of AI. It takes huge amounts of data to train AI systems. For example, to teach a computer how to accurately recognize vehicles, you need about 100 million example images of cars, trucks, buses, emergency vehicles, etc.[48] By 2030, China could be home to 30 percent of the world's data,[49] a tremendous advantage in fueling data mining, discovery and AI.

43. China's Technology Transfer Strategy: How Chinese Investments in Emerging Technology Enable A Strategic Competitor to Access the Crown Jewels of U.S. Innovation, Defense Innovation Unit Experimental, January 2018.

44. China's city of Tianjin to set up $16 billion artificial intelligence fund, Reuters, May 17, 2018.
45. Beijing to build $ billion AI research park, Reuters, January 3, 2018.
46. China's Technology Transfer Strategy: How Chinese Investments in Emerging Technology Enable A Strategic Competitor to Access the Crown Jewels of U.S. Innovation, Defense Innovation Unit Experimental, January 2018.
47. Top Artificial Intelligence Trends to Watch in 2018, CB Insights.
48. Testimony of Dr. Ian Buck, Vice President and General Manager of NVIDIA's Accelerated Computing Business, before the Subcommittee on Information Technology, Committee on Oversight and Government Reform, U.S. House of Representatives, February 14, 2018.
49. Battlefield Singularity: Artificial Intelligence, Military Revolution, and China's Future Military Power, Center for a New American Security, November 2017.

Figure 12. Portfolio of Policies and Practice to Develop China's Capabilities in Artificial Intelligence

Broad agenda of basic and cross disciplinary research

Domestic research centers

Research with foreign partners

National AI parks

Key technology development

Investment in foreign research centers

Development of cooperative platforms including supercomputing centers, data sets, and design and testing platforms

AI demonstrations and trials

International R&D cooperation

Promote application of AI in enterprises and factories

Emphasis on AI at all levels of education and training

Foreign mergers and acquisitions

Venture capital investments in start-ups at home and abroad

Hackerspaces and incubation services

Tax incentives

Standards development

Establish laws and regulation for development of AI

Intellectual property regimes

AI security

The United States does not have a comprehensive policy to address this massive technology transfer to China…The U.S. government does not have a holistic review of how fast this technology transfer is occurring, the level of Chinese investment in U.S. technology, or what technologies we should be protecting.

China's Technology Transfer Strategy,
Defense Innovation Unit Experimental

Can the U.S. System of Innovation Compete in this World of New Realities?

We are seeing changes in technology, competition and the global economy, historic in terms of their size, speed and scope. The United State faces hyper competition, a potential new global superpower competitor in China, and the prospect of economic and social disruption brought about by the unrelenting and accelerating march of technology.

Nevertheless, in a global economy ever more driven by technology and innovation, an enabling environment for innovation remains the advantage of only a few economies, with the United States in a position of significant strength:

- The United States remains the world's epicenter for disruptive innovation, thanks to its exceptional research infrastructure, and low barriers to entrepreneurs and start-ups.
- The United States remains the world leader in high-tech manufacturing.[50] It has a 31 percent global share and its output is growing. China has a 24 percent share. But, its output is also growing, surpassing Japan and the EU, and it is closing the gap with the United States. At 31 percent, the United States also has the highest global share of the $11.6 trillion value-added in commercial knowledge-intensive services, and our output is growing. The country with the next highest share is China, with 17 percent, but its output is growing faster.[51]
- The United States remains the world's largest investor in R&D, accounting for 28 percent of global R&D spending. It now invests a half trillion in R&D per year ($511B in 2016), and has built up a globally unparalleled national stock of science and technology.

The rapid development of AI will profoundly change human society and life, and change the world. In accordance with the requirements of the Chinese Communist Party Central Committee and the State Council, the national AI plan has been formulated to: seize the major strategic opportunity for the development of AI; build China's first-mover advantage in the development of AI; and accelerate the construction of an innovative nation and global power in science and technology.

50. Aircraft and spacecraft; computers, communications and semiconductors; testing, measuring and control instruments; and pharmaceuticals.

51. Science and Engineering Indicators 2018, National Science Foundation.

- Because the United States is by far the world's largest investor in basic research, it dominates patenting, sowing the seeds of future innovation, representing about one quarter of all international patent applications filed in 2016.[52]
- The United States has distinctive assets—its crown jewel national laboratories and top research universities. In a recent ranking, 17 of the world's top 25 research universities were in the United States.[53]
- In the U.S. innovation ecosystem, industry, start-ups, national labs and universities collaborate on R&D across the spectrum of science and technology.
- Vast amount of venture capital is pouring in to commercialize advanced technologies.
- The United States is seen as the global technology leader. A recent survey asked researchers across the world which country they considered to be the global leader in 12 advanced industries. The United States was named most often in 11 of the 12 industries, all by wide margins.[54]

Disrupt or Be Disrupted

Despite these significant U.S. strengths, the competitiveness of a wide range of nations—not to mention economic and technological change—is dynamic and ever transforming. And a country's comparative position can change rapidly. The source of a nation's long-term prosperity is the productivity with which it can utilize its human, capital and natural resources to produce goods and services. Now and into the future, U.S. companies, industries, and our national and regional economies that expect to compete will have to rise to the challenge and reorganize for this new age of disruption. Our government, communities and our education system must be prepared to support rapid change, and help those who are displaced or negatively affected by technological and competitive change.

When the United States controlled the direction of technology, we were positioned to control our economic destiny. That is no longer guaranteed. The United States must take stock. We must assess if our innovation ecosystem and its investments are enough to maintain our global economic and technological leadership. And, as technology seeps into nearly every aspect of American life, our national leaders and our governments at every level must bolster their knowledge and response capabilities to match the strengthening competition, technological change and disruptions that are coming.

52. Patent Cooperation Treaty Yearly Review 2017, World Intellectual Property Organization, 2017.
53. 2019 Times Higher Education Rankings.
54. R&D 2017 Global R&D Funding Forecast, Industrial Research Institute, Winter 2017; U.S. leads in advanced materials, agriculture/food, commercial aerospace, computing/IT, energy, environmental/sustainability, information/communications tech, instruments/electronics, healthcare, military/space/defense, pharmaceuticals/biotech; Japan leads in automotive, with U.S. in second place.

A Call to Action

What will the United States do in the face of these challenges at home and coming from abroad highlighted in the 2018 Clarion Call?

Will we plan for the long term, transforming challenge to opportunity? Will we put in place the talent, innovation capital and infrastructure necessary for continuing success in the decades to come? Will we recognize the multifaceted nature of this global innovation race, and come together across all sectors to form a new "innovation compact" for economic growth, productivity and inclusive prosperity?

To confront and overcome these critical challenges facing the U.S. innovation engine…

The create momentum in the United States to outpace the rest of the world in innovation capacity, capability and competitiveness…

To build on the Council's history of work in defining, articulating and activating America's innovation movement…

And to develop new partnerships and efforts to launch and scale innovation-based research, businesses and ventures in the United States…

The Board and Executive Committee of the Council call for the formation of a National Commission on Innovation and Competitiveness Frontiers to optimize the nation for a new, unfolding, evolving innovation reality that will shape the nation's prosperity for the next half century.

About the Council on Competitiveness

For more than three decades, the Council on Competitiveness (Council) has championed a competitiveness agenda for the United States to attract investment and talent, and spur the commercialization of new ideas.

While the players may have changed since its founding in 1986, the mission remains as vital as ever—to enhance U.S. productivity and raise the standard of living for all Americans.

The members of the Council—CEOs, university presidents, labor leaders and national lab directors—represent a powerful, nonpartisan voice that sets aside politics and seeks results. By providing real-world perspective to Washington policymakers, the Council's private sector network makes an impact on decision-making across a broad spectrum of issues from the cutting-edge of science and technology, to the democratization of innovation, to the shift from energy weakness to strength that supports the growing renaissance in U.S. manufacturing.

The Council's leadership group firmly believes that with the right policies, the strengths and potential of the U.S. economy far outweigh the current challenges the nation faces on the path to higher growth and greater opportunity for all Americans.

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