AMERICAN ACADEMY OF ARTS & SCIENCES

RICE UNIVERSITY'S BAKER INSTITUTE FOR PUBLIC POLICY

REPORT BRIEF

THE PERILS OF COMPLACENCY

America at a Tipping Point in Science & Engineering

An Update to

Restoring the Foundation: The Vital Role of Research in Preserving the American Dream

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AMERICAN ACADEMY OF ARTS & SCIENCES
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Acknowledgments

The American Academy's 2014 report *Restoring the Foundation: The Vital Role of Research in Preserving the American Dream* was produced by an expert committee chaired by Norman R. Augustine (Lockheed Martin Corporation, retired) and Neal Lane (Rice University). The committee and the project staff, working with a large range of partner organizations, devoted countless hours over the ensuing years to ensuring that the report's recommendations were discussed thoroughly with U.S. policy-makers and science and engineering leaders. While those efforts were productive, much remains to be done, and the world has changed markedly in ways that have profound implications for U.S. leadership in science, technology, and innovation.

The Academy is pleased to offer this five-year update to *Restoring the Foundation* that highlights significant developments, many of which were foreshadowed in the original report, and emphasizes actions that remain in urgent need of attention from U.S. policy leaders. I am grateful to the *Restoring the Foundation* committee, especially to Norm Augustine and Neal Lane, for their dedication to producing an informative and forceful document, as well as to the Academy staff members who worked on the report: John Randell, the John E. Bryson Director of Science, Engineering, and Technology Programs, and Amanda Vernon, Program Officer and Hellman Fellow in Science and Technology Policy.

This report has also benefited from substantial data collection and analysis by scholars from the Science and Technology Program at Rice University's Baker Institute for Public Policy, particularly Kirstin Matthews and Kenneth Evans. The American Academy and the *Restoring the Foundation* committee are grateful for the many hours that they devoted to compiling the data that underpin the arguments in the following pages. We offer our deep appreciation to the Kavli Foundation for helping to fund this report. Finally, we would like to thank Louise and John E. Bryson for their generous support of our Science, Engineering, and Technology programs; John also served on the Committee on New Models for U.S. Science & Technology Policy that gave rise to the *Restoring the Foundation* report.

The COVID-19 pandemic, which began to unfold as this report neared its publication, has only underscored our vital need for a robust and innovative American scientific enterprise. I join with all the contributors to this report in urging that those arguments be given full consideration by America's leaders.

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President, American Academy of Arts and Sciences

American Academy of Arts and Sciences

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Executive Summary

At the very moment this report was being written, China[1] was passing the United States in research and development (R&D) investment (at purchasing power parity, PPP) (Figure 1).[2] Yet this is an era in which a vast majority of the growth in America's economy (gross domestic product, GDP) and all that it supports is attributable to advancements in science and technology. Indeed, we live in what is not infrequently referred to as the Age of Technology. But, astonishingly, headlines in the media make no note of this watershed event, nor has the topic been raised in presidential debates. The nation seems oblivious to the consequences of what is occurring – and what will follow.

Other recent developments are placing additional stress on the U.S. research system even as they underscore its indispensability in providing the fuel for American innovation and competitiveness as well as the know-how required to address the nation's many societal challenges. As this report was being prepared, a major coronavirus outbreak was impacting thousands of lives in China, America, and other parts of the world. Meanwhile, security concerns have led some policy-makers to propose draconian restrictions on the very same foreign researchers on whom we have come to rely to fill the persistent domestic talent gap in science and engineering. One result of recent and proposed immigration restrictions is that other countries have become more competitive at attracting workers – and U.S. corporations are more inclined to move R&D laboratories to other countries. Compounding this problem is a continued weakness in U.S. support for basic and applied research; the FY2021 Presidential Budget Request would cut federal support for these categories by $7.9 billion, or just over 9 percent.[3]

The global pace of scientific and technological (S&T) discovery is accelerating. Today, global leadership in science and technology is measured in months

1. All references to "China" in this report are to the People's Republic of China, rather than the Republic of China, aka Taiwan.

2. For additional analysis, see Task Force on American Innovation, "Benchmarks 2019: Second Place America? Increasing Challenges to US Scientific Leadership" (Washington, D.C.: Task Force on American Innovation, 2019), http://www.innovationtaskforce.org/benchmarks2019/.

3. Matt Hourihan, "Latest White House Budget Features A Few Big Research Priorities Amid Ranging Reductions," February 10, 2020, https://www.aaas.org/news/latest-white-house-budget-features-few-big-research-priorities-amid-ranging-reductions.

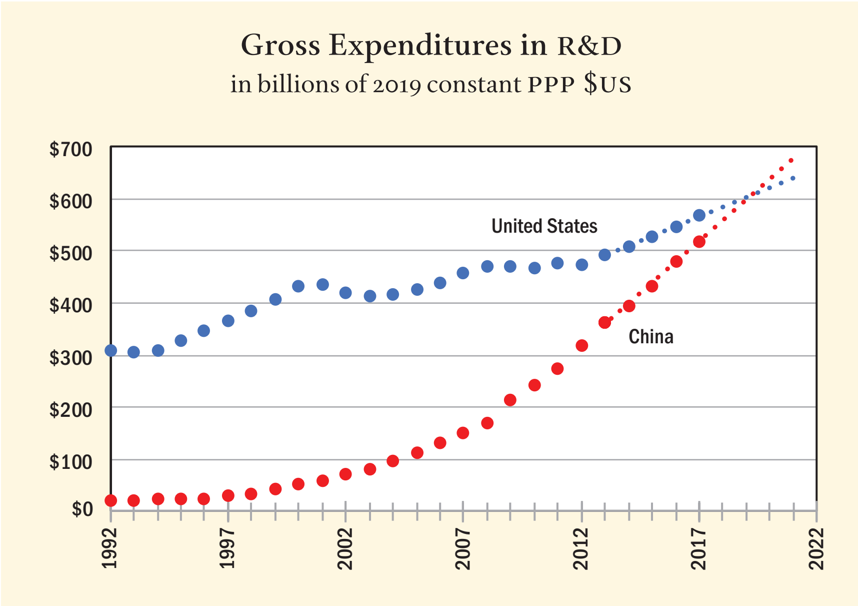

Figure 1

Gross Expenditures in R&D in billions of 2019 constant PPP $US

Adapted from National Science Board, "National Science Board Statement on Global R&D Investments NSB-2018-9," February 17, 2018.

Source: OECD. 2019. "Main Science and Technology Indicators," OECD Science, Technology and R&D Statistics (database), https://doi.org/10.1787/data-00182-en.

Constant dollars are calculated using total nondefense composite outlay deflators found in Table 10-1: Office of Management and Budget. 2019. "Fiscal Year 2020 GDP and Deflators," https://www.whitehouse.gov/omb/historical-tables/.

Note: FY2017 and FY2018 include a new definition for R&D, which excludes DOD's late-stage development, testing, and evaluation "development" category, formerly included. Trend lines are linear fit of last five points extended four years.

or years, not decades or centuries. For example, the time between doubling computing capacity on that critical element of virtually all modern electronic devices – the semiconductor integrated circuit – is just a small number of years.[4] The half-life of articles published in scientific journals, as measured by the frequency at which they are referenced, is five years or less in many fields.[5]

4. "Moore's Law and Intel Innovation," Intel, https://www.intel.com/content/www/us/en/history/museum-gordon-moore-law.html.

5. John Bohannon, "The Secret Half-Lives of Scientific Papers," *Science*, December 19, 2013, https://www.sciencemag.org/news/2013/12/secret-half-lives-scientific-papers.

"The history of modernization is, in essence, a history of scientific and technological progress. Scientific discovery and technological inventions have brought about new civilizations, modern industries, and the rise and fall of nations. . . . I firmly believe that science is the ultimate revolution."

– Wen Jiabao, former Premier of the State Council of the People's Republic of China

To fall behind even a few years in S&T R&D can have grave consequences for a country's economy, job creation, standard of living, and national security.

The United States became a world power – economically, militarily, and culturally – in significant part by placing a high priority on innovation, fueled by advances in science and technology. This priority, in turn, required investing in R&D, especially fundamental research conducted in universities and national laboratories across the fields of science, technology, engineering, medicine, and mathematics.

China is projected to become the world's largest economy when measured by GDP by 2030.[6] By 2026, the 250th anniversary of the United States, China's strategic plan calls for it to be well on its way to becoming the unchallenged world leader in science, technology, and innovation. These developments are perilous for America, which today, 50 years after the *Apollo 11* moon landing, is at a tipping point in R&D.

The well-being of America and its individual citizens depends heavily on the strength of America's economy, which, in turn, depends heavily on research and development. Without a strong economy, jobs disappear – along with the tax receipts needed to provide healthcare, social security, education, infrastructure, and homeland and national security. Numerous studies, including two that won Robert Solow and Paul Romer the Nobel Prize in Economics in

6. Callum Paton, "World's Largest Economy in 2030 Will Be China, Followed by India, with U.S. Dropping to Third, Forecasts Say," *Newsweek*, January 10, 2019, https://www.newsweek.com/worlds-largest-economy-2030-will-be-china-followed-india-us-pushed-third-1286525.

1987 and 2018, respectively, have concluded that as much as 85 percent of the long-term growth in America's economy (measured by GDP) is attributable to advancements in just two closely related fields: science and technology.[7]

Five years ago, a study committee of the American Academy of Arts and Sciences prepared the report *Restoring the Foundation: The Vital Role of Research in Preserving the American Dream* (referred to herein as RtF1).[8] The report examined the state of American innovation policy and informed the bipartisan American Innovation and Competitiveness Act, which Congress passed by unanimous consent in December 2016 and President Barack Obama signed into law in January 2017. The Academy and other organizations worked with corporate leaders to issue a call to action, "Innovation: An American Imperative," that was signed by more than 500 major businesses, universities, scientific societies, and other organizations.[9]

The present committee is guardedly encouraged by this strengthening of our national understanding of the importance of R&D and by recent increases in federal research funding in some areas, the FY2021 budget request notwithstanding. Yet the challenges within the United States, along with rising government investment by China and other countries, remain basically unchanged. This report presents a comprehensive update on America's situation and provides policy recommendations that, if enacted, would help ensure that the United States does not lose the preeminent position in discovery and innovation that it has built through investments and efforts since the end of World War II.

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7. "The Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel 1987," The Nobel Prize, https://www.nobelprize.org/prizes/economic-sciences/1987/summary/; "Paul M. Romer: Facts," The Nobel Prize, https://www.nobelprize.org/prizes/economic-sciences/2018/romer/facts/; C.I. Jones, "The Facts of Economic Growth," in *Handbook of Macroeconomics* (Amsterdam: Elsevier, 2016), 2:3–69, https://doi.org/10.1016/bs.hesmac.2016.03.002; and Robert Solow, "Technical Change and the Aggregate Production Function," *The Review of Economics and Statistics* 39 (3) (1957): 312–320, https://doi.org/10.2307/1926047.

8. *Restoring the Foundation: The Vital Role of Research in Preserving the American Dream* (Cambridge, Mass.: American Academy of Arts and Sciences, 2014), http://www.amacad.org/restoringthefoundation.

9. "Innovation: An American Imperative," http://www.innovationimperative.org/.

AMERICA AT A TIPPING POINT

America's total national investment in research and development as a fraction of GDP has remained stagnant at 2.4–2.7 percent for nearly half a century (Figure 2).[10] Meanwhile, other nations, especially China, have accelerated such investments. Because of America's tepid response to rising competition from abroad, the United States has fallen to tenth place among Organisation for Economic Co-operation and Development (OECD) nations in investment in R&D (public and private) as a fraction of GDP.[11]

While national R&D spending as a fraction of GDP is but one metric of developed economies that are largely driven by advances in science and technology, the ratio is a strong indicator of the intensity of a nation's investment in its future. The rapid drop in global ranking of the United States in R&D as a fraction of GDP reflects government policy-makers, corporate boards, and CEOs focusing on near-term issues at the expense of longer-term, potentially existential issues. That is perhaps to be expected, given the short-term incentives that drive politics and business today, but it does not bode well for the future of a country in a world where others, particularly China, are committed to, and investing in, long-term strategies for success – if not outright dominance.

THE INGREDIENTS OF INNOVATION: CHINA AND THE UNITED STATES

The United States cannot compete with China through the size of its workforce, where China possesses a major advantage, but rather must compete through creativity and innovation. Yet China is gaining the upper hand in the latter as well, closing in or surpassing the United States in measures including gross R&D spending, funding for basic research, patents granted,

10. "Historical Trends in Federal R&D," American Association for the Advancement of Science, https://www.aaas.org/programs/r-d-budget-and-policy/historical-trends-federal-rd.

11. Because of past variations in its definition of R&D, Switzerland has not been included in the figure. Were it to be included, the United States would be in 11th place.

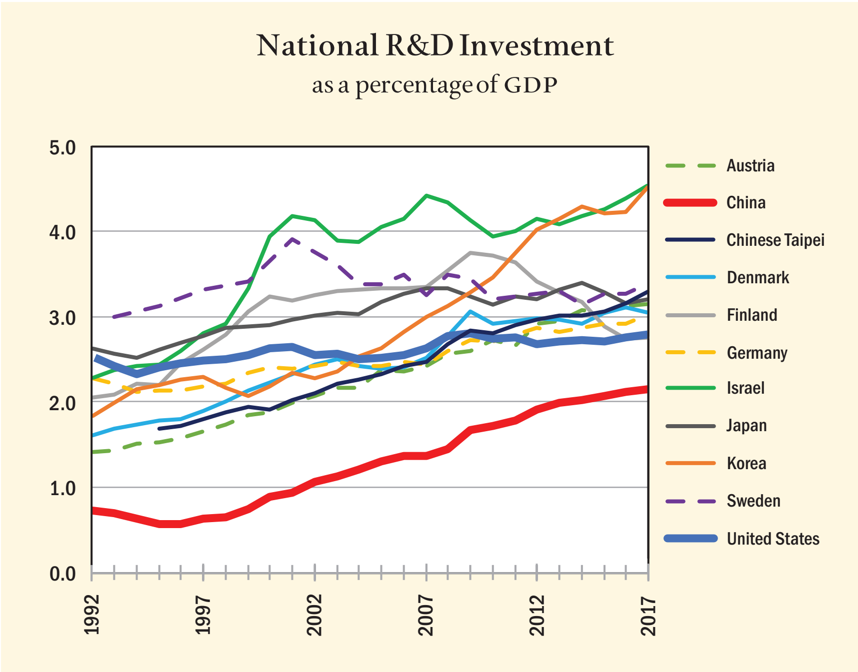

Figure 2

National R&D Investment as a Percentage of GDP

Source: OECD, "Main Science and Technology Indicators," 2019, OECD Science, Technology and R&D Statistics (database), https://doi.org/10.1787/data-00182-en.

S&E articles published, S&E bachelor's degrees and doctorates awarded, and researchers employed (Figure 3).

Innovation through science and technology has four fundamental and closely interrelated components: 1) human capital; 2) knowledge capital; 3) an ecosystem conducive to innovation; and 4) financial capital. The following paragraphs examine innovation in China and the United States using these four metrics.

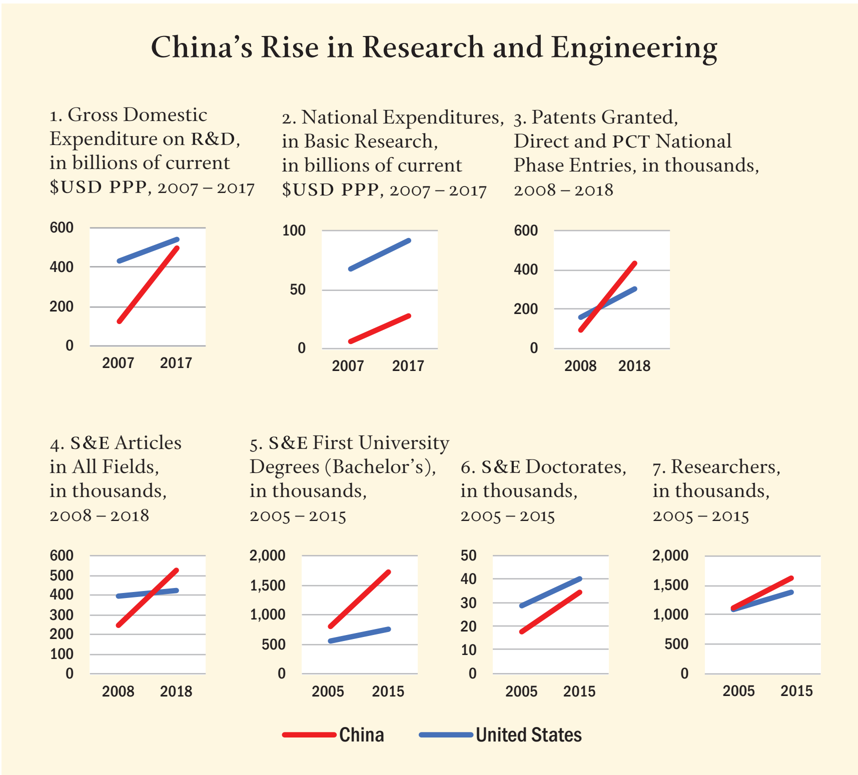

Figure 3

China's Rise in Research and Engineering

Source: 1. OECD, "Main Science and Technology Indicators," 2019, OECD Science, Technology and R&D Statistics (database), https://doi.org/10.1787/data-00182-en.

2. Ibid.

3. World Intellectual Property Organization. 2019. "WIPO Statistics Database," https://www3.wipo.int/ipstats/index.htm?tab=patent.

4. National Science Board, *Science & Engineering Indicators 2020* (Alexandria, Va.: National Science Foundation, 2020), https://ncses.nsf.gov/indicators.

5. Ibid.

6. Ibid.

7. National Science Board, *Science & Engineering Indicators 2018* (Alexandria, Va.: National Science Foundation, 2018), https://www.nsf.gov/statistics/2018/nsb20181/.

Human Capital

Today, China awards more bachelor's degrees in science and engineering than the United States, the European Union (EU), and Japan combined, having bypassed the United States in 2003.[12] To keep pace with demand, China is projected to continue to increase the numbers of S&E graduates substantially. The number of corresponding degrees awarded by U.S. institutions continues to be relatively flat (Figure 4a).[13] A substantial share of those degrees goes to international, frequently Chinese, citizens. China remains behind the United States in the production of S&E graduates with doctorates from its own universities (Figure 4b) but is rapidly increasing these numbers, and Chinese university rankings are increasing as well.[14]

Lesser interest in science, technology, engineering, and mathematics (STEM) careers among America's youth is exacerbated by the inadequacy of the nation's precollege educational system.[15] The Program for International Student Assessment (PISA), which tests 15-year-olds in reading, mathematics, and science, finds U.S. students are ranked 25th among OECD nations (Figure 5).

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12. "S&E" includes engineering, physical sciences, environmental sciences, mathematical sciences, computer sciences, life sciences, psychological sciences, and social sciences. See "S&E Field Classification," National Science Foundation, https://www.nsf.gov/statistics/rdexpenditures/glossary/s_efield.htm.

13. National Science Board, *Science and Engineering Indicators 2018*, NSB-2018-1 (Alexandria, Va.: National Science Foundation, 2018), 2-47–2-60, https://nsf.gov/statistics/2018/nsb20181/report.

14. "China, Japan Raise Pressure on US, UK in Global Ranking," *University World News*, September 12, 2019, https://www.universityworldnews.com/post.php?story=20190912131138561.

15. Brian Kennedy, Meg Hefferon, and Cary Funk, "Half of Americans Think Young People Don't Pursue STEM Because It Is Too Hard," *Fact Tank*, January 17, 2018, Pew Research Center, https://www.pewresearch.org/fact-tank/2018/01/17/half-of-americans-think-young-people-dont-pursue-stem-because-it-is-too-hard/; and Olga Khazan, "Lack of Interest and Aptitude Keeps Students Out of STEM Majors," *Washington Post*, January 6, 2010, https://www.washingtonpost.com/blogs/on-small-business/post/lack-of-interest-and-aptitude-keeps-students-out-of-stem-majors/2012/01/06/gIQAoDzRfP_blog.html.

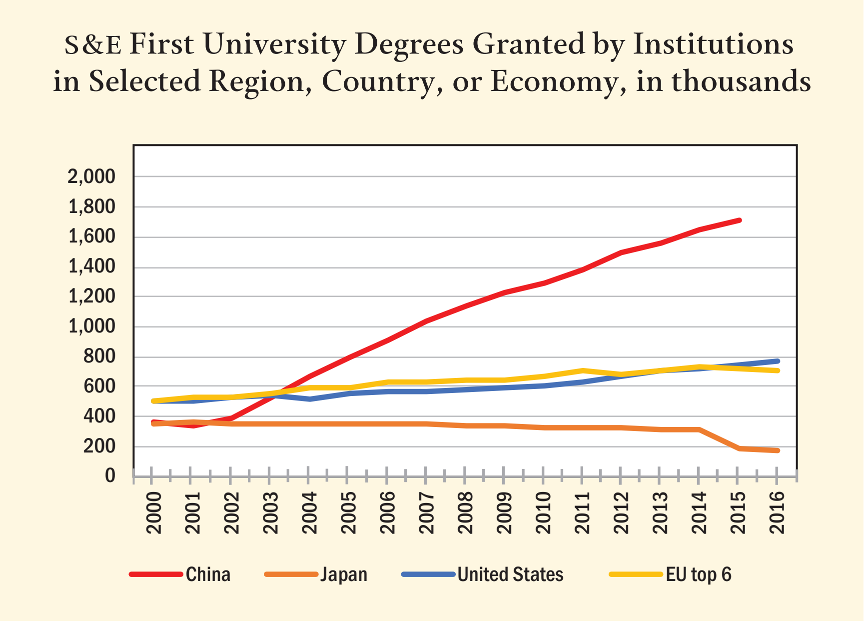

Figure 4a

S&E First University Degrees Granted by Institutions in Selected Region, Country, or Economy, in thousands

Source: Reproduced from Figure 2-19 in National Science Board, *Science & Engineering Indicators 2020* (Alexandria, Va.: National Science Foundation, 2020).

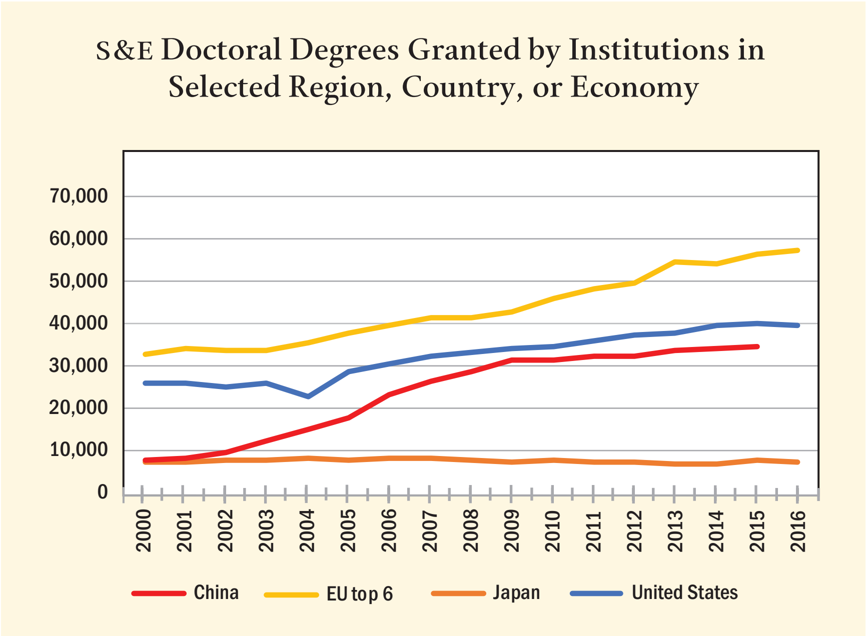

Figure 4b

S&E Doctoral Degrees Granted by Institutions in Selected Region, Country, or Economy

Source: Reproduced from Figure 2-21 in National Science Board, *Science & Engineering Indicators* 2020 (Alexandria, Va.: National Science Foundation, 2020).

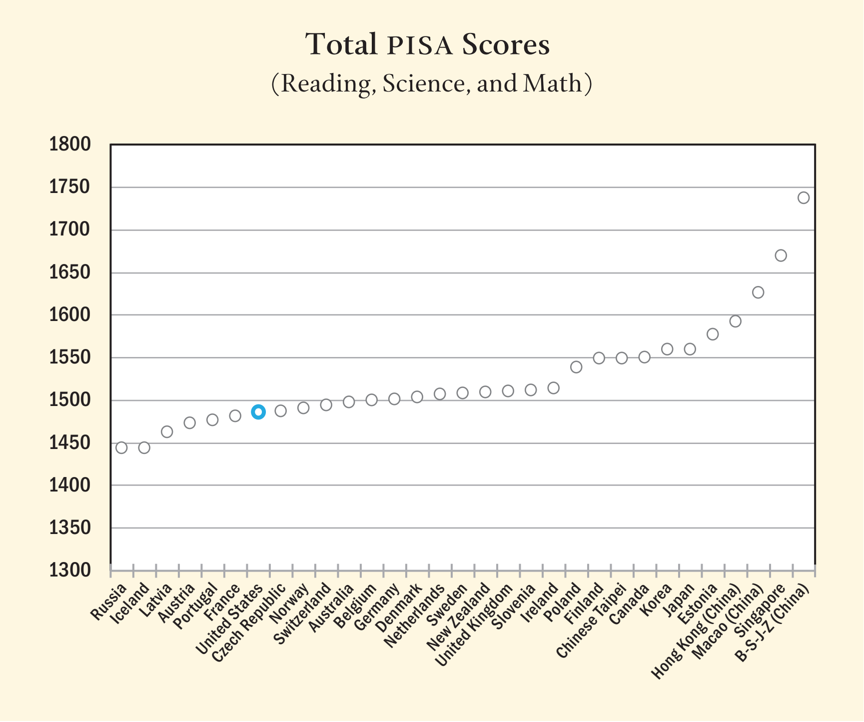

Figure 5

Total PISA Scores (Reading, Science, and Math)

Source: OECD, "Main Science and Technology Indicators," 2019; PISA 2018 Results (Volume I): *What Students Know and Can Do*, https://doi.org/10.1787/19963777.

Note: B-S-J-Z refers to four PISA participating China provinces: Beijing, Shanghai, Jiangsu, and Guangdong.

Compounding the issue of overall poor domestic K-12 STEM education, the United States is systematically failing to attract Americans of diverse backgrounds into STEM careers, whether measured by gender, race, socioeconomic status, sexual orientation, disability, religion, or geographic location within the United States.[16] If not addressed, this underrepresentation will continue to hamper U.S. efforts to develop a strong domestic STEM workforce, especially as historically underrepresented groups become an increasing proportion of the overall U.S. population.

U.S. academic research in STEM fields relies heavily on foreign-born individuals from China, India, and other parts of the world. In recent years, about one-third of U.S. Ph.D. STEM graduates have not been U.S. citizens or permanent residents, and 28 percent of U.S. S&E faculty were born overseas, as were over half of U.S.-trained S&E postdoctoral workers.[17] Nearly half of U.S. Fortune 500 companies were founded by immigrants or children of immigrants.[18] Similarly, 26 percent of the members of the U.S. National Academy of Sciences and 31 percent of the members of the U.S. National Academy of Engineering are foreign-born.

Demand for workers in the STEM fields continues to be very high, and the United States continues to be extremely dependent upon immigration of talented men and women to meet this demand. While there is no standard definition of the STEM workforce, the American Immigration Council (AIC) uses both a narrow definition – physical and life sciences, engineering, mathematics, and computer science – and a broader definition that adds physicians, nurses, and social scientists. According to the AIC, in 2015 STEM workers (nar-

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16. National Science and Technology Council Committee on STEM Education, *Charting a Course for Success: America's Strategy for STEM Education* (Washington, D.C.: National Science and Technology Council, December 2018), https://www.whitehouse.gov/wp-content/uploads/2018/12/STEM-Education-Strategic-Plan-2018.pdf.

17. National Science Board, *Science and Engineering Indicators 2018*, 2-61–2-85, https://nsf.gov/statistics/2018/nsb20181/report/sections/higher-education-in-science-and-engineering/graduate-education-enrollment-and-degrees-in-the-united-states.

18. Ian Hathaway, "Almost Half of Fortune 500 Companies Were Founded by American Immigrants or Their Children," *The Avenue*, December 4, 2017, Brookings Institution, https://www.brookings.edu/blog/the-avenue/2017/12/04/almost-half-of-fortune-500-companies-were-founded-by-american-immigrants-or-their-children/.

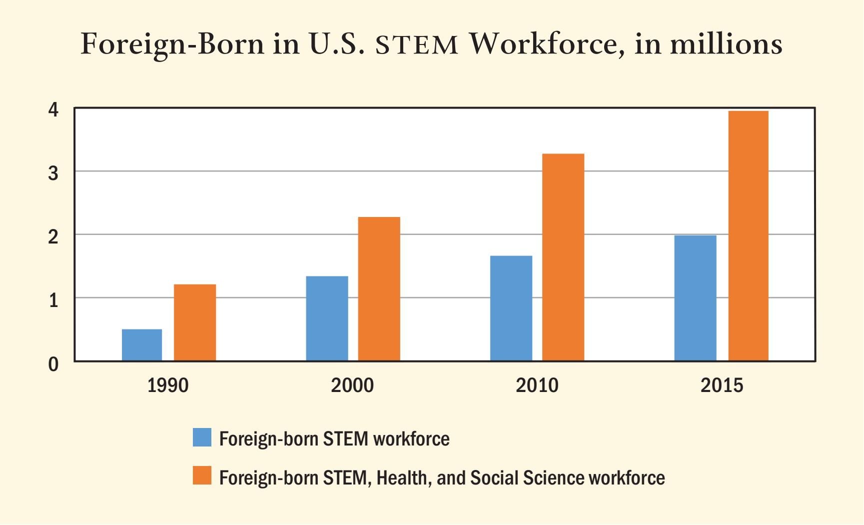

Figure 6a

Foreign-Born in U.S. STEM Workforce, in millions

Source: American Immigration Council, "Foreign-Born STEM Workers in the United States," 2018, https://www.americanimmigrationcouncil.org/research/foreign-born-stem-workers-united-states.

row definition) made up about 5 percent (approximately 8 million) of the total U.S. workforce, and 24 percent (approximately 2 million) of STEM workers (narrow definition) were foreign-born (Figure 6a).[19] These data do not include academic positions, many of which are held by foreign-born faculty.[20]

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19. American Immigration Council, *Foreign-Born STEM Workers in the United States* (Washington, D.C.: American Immigration Council, June 14, 2017), Table 2, https://www.americanimmigrationcouncil.org/research/foreign-born-stem-workers-united-states.

20. National Science Board, *Science and Engineering Indicators 2018*, NSB-2018-1 (Alexandria, Va.: National Science Foundation, 2018), 2-47–2-60, https://nsf.gov/statistics/2018/nsb20181/report. See Appendix Table 5-17.

In the academic year 2017 – 2018, about 280,000 men and women from China were enrolled in U.S. colleges and universities as undergraduate or graduate students, amounting to about one-third of all international students studying in the United States.[21] Second to China in terms of total U.S. undergraduate and graduate enrollment is India (120,000), followed by South Korea (44,000) and Saudi Arabia (39,000).[22] Strikingly, the percentage of Chinese students who return to China following their studies has increased markedly over the past decade (Figure 6b),[23] representing a loss of talent for the countries who train them, including the United States.

Members of Congress, U.S. intelligence officials, and others have raised concerns that China's government – through its consulates – is directing some Chinese students and visiting researchers to steal intellectual property and spread pro-China political propaganda on America's campuses. There is clear evidence that both are happening, at least to some degree. The U.S. Federal Bureau of Investigation (FBI) has issued warnings about China's talent programs and espionage.[24] According to a senior U.S. Department of Justice official, over 90 percent of U.S. economic espionage prosecutions include individuals or firms from mainland China.[25] FBI officials have visited various universities to provide briefings on the attendant risks, and research has documented isolated incidents of Chinese students attempting to pressure fellow Chinese students,

21. "International Student Data," IIE, https://opendoorsdata.org/data/international-students/academic-level-and-places-of-origin/.

22. "Places of Origin," IIE, https://opendoorsdata.org/data/international-students/academic-level-and-places-of-origin/.

23. Brief Report on Chinese Overseas Students and International Students in China, March 31, 2018, http://en.moe.gov.cn/documents/reports/201901/t20190115_367019.html.

24. "FBI Counterintelligence Note: Chinese Talent Programs," Public Intelligence, August 11, 2016, https://publicintelligence.net/fbi-chinese-talent-programs/.

25. Adam S. Hickey, remarks at the Fifth National Conference on CFIUS and Team Telecom, Washington, D.C., Wednesday, April 24, 2019. Text available at https://www.justice.gov/opa/speech/deputy-assistant-attorney-general-adam-s-hickey-national-security-division-delivers-0, accessed February 24, 2020.

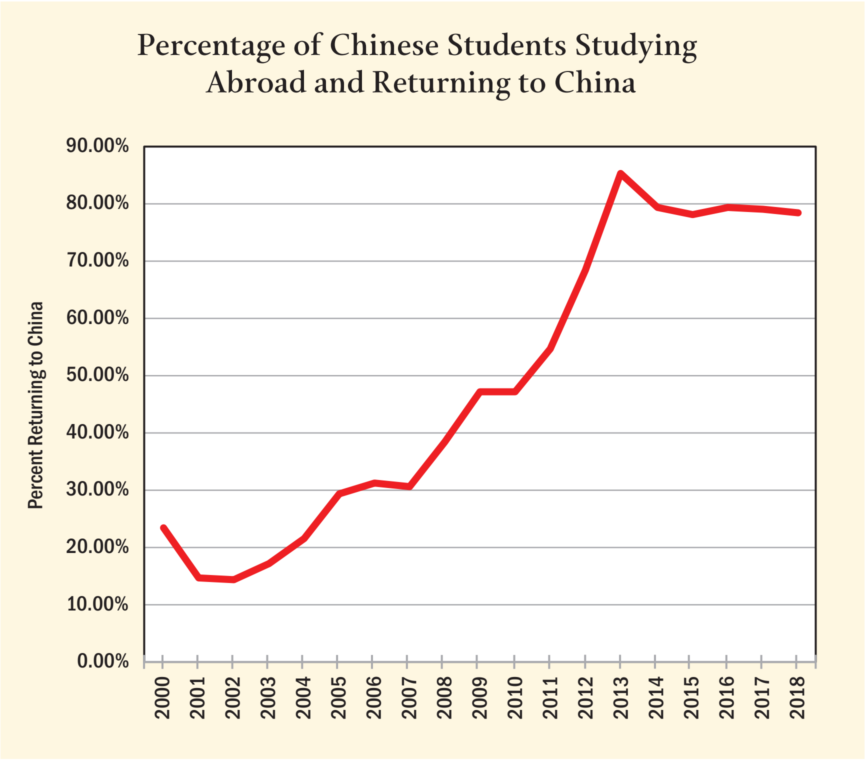

Figure 6b

Percentage of Chinese Students Studying Abroad and Returning to China

Source: National Bureau of Statistics of China, China Statistic Yearbook 2019.

faculty, and administrators viewed as critical of China.[26] University leaders are working with federal officials to ensure that any new policies do not undercut the openness that has always been a fundamental strength of American higher education.[27]

Altogether, the benefits of foreign-born individuals contributing to U.S. science and technology far outweigh the risks.[28] Recognizing this, the committee concludes that an appropriate solution is not blanket prohibitions within basic research, as some have proposed, but rather enhanced alertness and action in cases where evidence indicates violation of U.S. law. This, of course, applies to domestic as well as foreign-born individuals.

Knowledge Capital

There is no agreed-upon single measure of knowledge capital; however, commonly used metrics include the numbers and quality of publications and patents.

The publication of scientific discoveries in peer-reviewed journals is a principal mechanism for the dissemination of research.[29] Historically, the United

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26. Emily Feng, "FBI Urges Universities to Monitor Some Chinese Students and Scholars in the U.S.," NPR, June 28, 2019, https://www.npr.org/2019/06/28/728659124/fbi-urges-universities-to-monitor-some-chinese-students-and-scholars-in-the-u-s; Bethany Allen-Ebrahimian, "China's Long Arm Reaches into American Campuses," *Foreign Policy*, March 7, 2018, https://foreignpolicy.com/2018/03/07/chinas-long-arm-reaches-into-american-campuses-chinese-students-scholars-association-university-communist-party/; and Anastasya Lloyd-Damnjanovic, *A Preliminary Study of PRC Political Influence and Interference Activities in American Higher Education* (Washington, D.C.: Wilson Center, September 6, 2018), https://www.wilsoncenter.org/publication/preliminary-study-prc-political-influence-and-interference-activities-american-higher.

27. Lee C. Bollinger, "No, I Won't Start Spying on My Foreign-Born Students," *Washington Post*, August 30, 2019, https://www.washingtonpost.com/opinions/no-i-wont-start-spying-on-my-foreign-born-students/2019/08/29/01c80e84-c9b2-11e9-a1fe-ca46e8d573c0_story.html.

28. JASON, "Fundamental Research Security," JSR-19-2I, December 2019, https://www.nsf.gov/news/special_reports/jasonsecurity/JSR-19-2IFundamentalResearchSecurity_12062019FINAL.pdf.

29. Ewen Callaway, "Beat It, Impact Factor! Publishing Elite Turns against Controversial Metric," *Nature* 535 (2016): 210–211, https://doi.org/10.1038/nature.2016.20224.

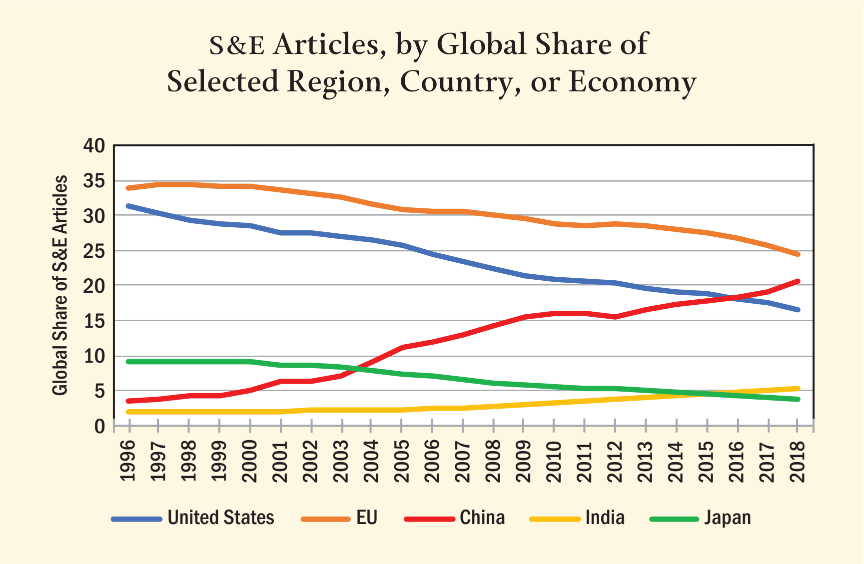

Figure 7a

S&E Articles, by Global Share of Selected Region, Country, or Economy

Source: Reproduced from Figure 5a-3 in National Science Board, *Science & Engineering Indicators 2020* (Alexandria, Va.: National Science Foundation, 2020).

States has ranked first in the number of research publications, as well as the number of publications in the most highly cited journals. However, in 2016, China passed the United States in the number of research articles published, and it is rapidly rising in the number of articles published in the most recognized journals (Figure 7a and Figure 7b).

One measure of the effectiveness of the transition from research discovery to practical application is the number of patents granted, a category in which China has taken the lead in recent years (Figure 8). However, the large fraction of Chinese patents that go unrenewed after five years calls into question the value of many of those patents in the first place.

Innovation Ecosystem

Today is a time of unprecedented opportunity for scientific discovery and rapid advances in technology and its applications. Research discoveries lead

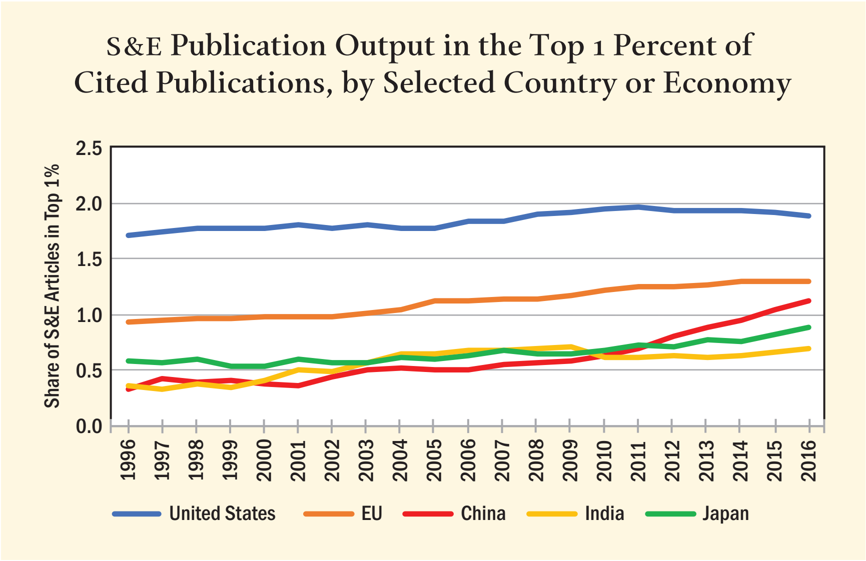

Figure 7b

S&E Publication Output in the Top 1 Percent of Cited Publications, by Selected Country or Economy

Source: Reproduced from Figure 5a-9 in National Science Board, *Science & Engineering Indicators 2020* (Alexandria, Va.: National Science Foundation, 2020).

to new technologies, and new technologies provide tools that in turn accelerate research discovery. And this is happening at an accelerating pace. Examples include big data, artificial intelligence (AI), machine learning, quantum technology, CRISPR, genomic medicine, medical imaging, robotics, high-performance materials, nanotechnology, and much, much more. The sciences have been described as undergoing a "revolution" that, to achieve meaningful progress, requires a significant and purposeful convergence of methods and approaches from scientists and engineers across fields and industries.[30]

30. *Convergence: The Future of Health* (Washington, D.C.: MIT Washington Office, June 2016), http://www.convergencerevolution.net/s/Convergence-The-Future-of-Health-2016-Report-55pf.pdf.

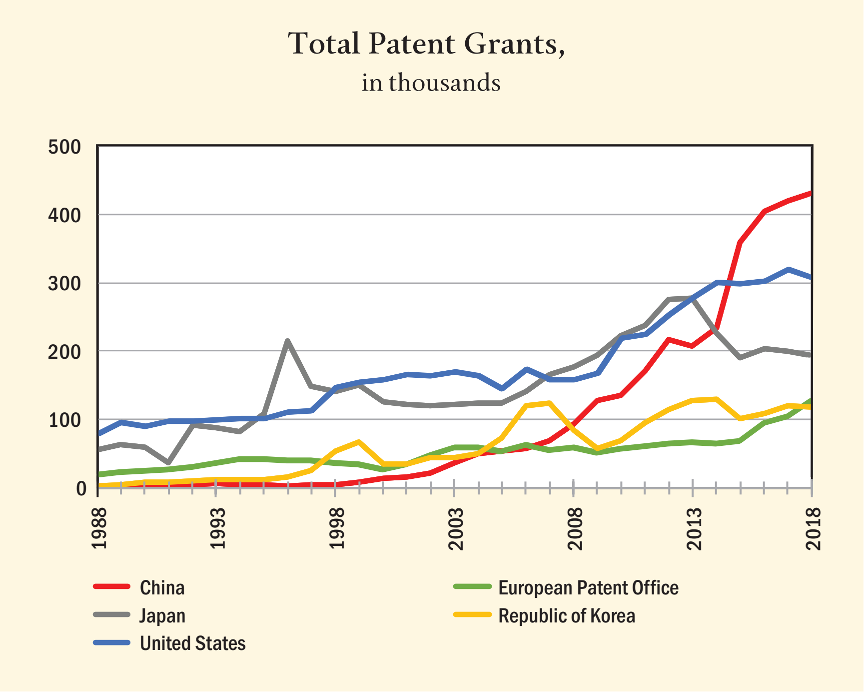

Figure 8

Total Patent Grants, in thousands

Source: World Intellectual Property Organization, "WIPO Statistics Database," 2019, https://www3.wipo.int/ipstats/index.htm?tab=patent.

Note: Includes both total patent grants and Patent Cooperation Treaty national phase entries.

One measure of how the United States compares to the rest of the world in innovation is its ranking on the Bloomberg Innovation Index. In Bloomberg's 2019 assessment, the United States ranks eighth overall, tenth in R&D intensity (national R&D spending as a percentage of GDP), 28th in researcher concentration (professionals engaged in R&D per capita), 25th in manufacturing value added, 43rd in tertiary efficiency[31] (principally the fraction of individuals receiving tertiary – university or college – education),[32] and 76th in the fraction of initial degrees awarded in engineering.

The World Intellectual Property Organization (WIPO), an agency of the United Nations, publishes a Global Innovation Index (GII) based on its assessment of 80 indicators of innovation performance in 126 countries, including such metrics as political environment, education, infrastructure, and business sophistication. In the 2018 report, which focuses on energy innovation, China advanced to 17th place because of "an economy witnessing rapid transformation guided by government policy prioritizing R&D–intensive ingenuity." In contrast, the United States slipped from fourth to sixth place in one year. The United States was in first place as recently as 2008.[33]

Even in cases where the United States performed significant early research, markets and jobs have been lost to others because of barriers (regulations, laws, taxes, etc.) to the rapid transition of new knowledge into products and services. Examples of this occurrence include solar cells, batteries, television, and 5G communications. As the pace of transition from the laboratory to the market accelerates, the U.S. position becomes increasingly endangered (Figure 9).

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31. Michelle Jamrisko and Wei Lu, "The U.S. Drops Out of the Top 10 in Innovation Ranking," *Bloomberg*, January 22, 2018, https://www.bloomberg.com/news/articles/2018-01-22/south-korea-tops-global-innovation-ranking-again-as-u-s-falls; and Michelle Jamrisko, Lee J. Miller, and Wei Lu, "These Are the World's Most Innovative Countries," *Bloomberg*, January 22, 2019, https://www.bloomberg.com/news/articles/2019-01-22/germany-nearly-catches-korea-as-innovation-champ-u-s-rebounds.

32. The index bases its ranking on the following criterion: "Postsecondary education: Number of secondary graduates enrolled in postsecondary institutions as a percentage of cohort; percentage of labor force with tertiary degrees; annual science and engineering graduates as a percentage of the labor force and as a percentage of total tertiary graduates." See Jamrisko et al., "These Are the World's Most Innovative Countries." The United States is penalized by the six-year graduation rate at public universities of only 60 percent.

33. Cornell University, INSEAD, and WIPO, *Global Innovation Index 2018: Energizing the World with Innovation* (Geneva: WIPO, 2018), http://www.wipo.int/publications/en/details.jsp?id=4330; http://www.wipo.int/pressroom/en/articles/2018/article_0005.html; https://www.globalinnovationindex.org/userfiles/file/GII-2008-2009-Report.pdf.

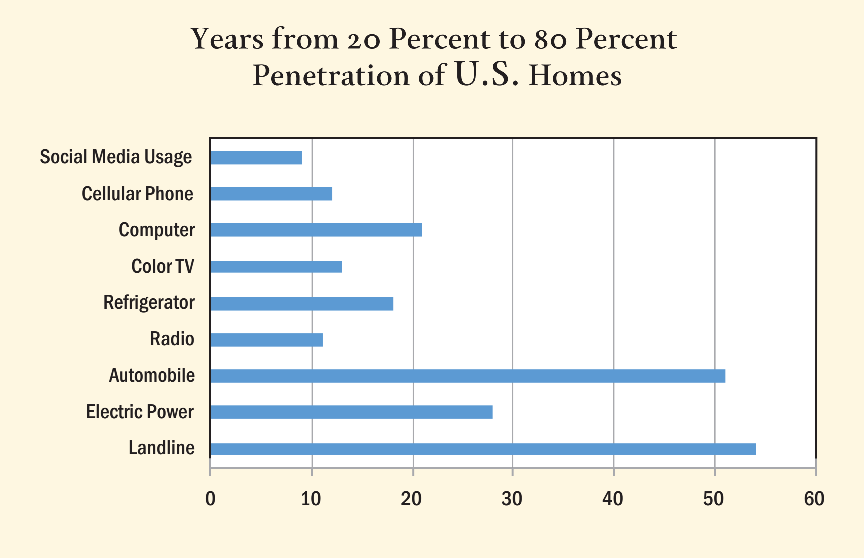

Figure 9

Years from 20 Percent to 80 Percent Penetration of U.S. Homes

Source: Hannah Ritchie and Max Roser, "Technology Adoption," 2019, https://ourworldindata.org/technology-adoption, accessed February 13, 2020.

Financial Capital

The United States, with a GDP in 2018 of approximately $20 trillion, has the largest economy in the world based on current exchange rates.[34] China is the world's second largest economy by this particular measure, and analyses project that China will close the gap with the United States by 2030.[35] China passed

34. Noah Smith, "Who Has the World's No. 1 Economy? Not the U.S.," *Bloomberg*, October 18, 2017, https://www.bloomberg.com/opinion/articles/2017-10-18/who-has-the-world-s-no-1-economy-not-the-u-s.

35. Callum Paton, "World's Largest Economy in 2030 Will Be China, Followed by India, with U.S. Dropping to Third, Forecasts Say," *Newsweek*, January 10, 2019, https://www.newsweek.com/worlds-largest-economy-2030-will-be-china-followed-india-us-pushed-third-1286525.

the United States in GDP adjusted for purchasing power parity in 2014.[36] China became a member of the World Trade Organization in 2001 and in a single decade, from 2008 to 2018, the number of Chinese Global Fortune 500 companies rose from 29 to 120, while the number of U.S. companies fell from 153 to 126 (Figure 10). China is on a path to pass the United States by this latter measure in the very near future, if it has not already done so.

In the United States, pressures from stockholders tend to encourage publicly held companies to favor investments that promote near-term increases in stock price as opposed to long-term returns, thereby discouraging investments in such areas as infrastructure and research.[37]

The task of laying the groundwork needed to ensure that the United States continues to be a country of scientific discovery and innovation has thus increasingly fallen to the U.S. federal government.[38] However, federal spending (annual outlays) for R&D have remained generally flat at about 4 percent of total federal spending and about 10 percent of discretionary spending for more than 30 years (Figure 11).[39] With the federal government's redefinition of *development* in fiscal year 2018 to exclude "pre-production development" and other nonexperimental work, these percentages have moved even lower.[40]

In contrast to the United States, overall R&D spending in China has increased significantly over the past two decades. From 2000 to 2012, R&D spending as a percentage of GDP increased by 18 percent per year in China (Figure 2). China

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36. https://data.worldbank.org/indicator/NY.GDP.MKTP.PP.CD?locations=US-CN-1W, accessed on February 13, 2020.

37. Beatriz Pessoa de Araujo and Adam Robbins, "The Modern Dilemma: Balancing Short- and Long-Term Business Pressures," Harvard Law School Forum on Corporate Governance, June 20, 2019, https://corpgov.law.harvard.edu/2019/06/20/the-modern-dilemma-balancing-short-and-long-term-business-pressures/.

38. Ben S. Bernanke, "Promoting Research and Development: The Government's Role" (speech at the New Building Blocks for Jobs and Economic Growth conference, Washington, D.C., May 16, 2011), https://www.federalreserve.gov/newsevents/speech/bernanke20110516a.htm.

39. "Historical Trends in Federal R&D."

40. Matt Hourihan, "The Federal Government Is Tweaking What Counts as R&D: Q&A," American Association for the Advancement of Science, June 13, 2018, https://www.aaas.org/news/federal-government-tweaking-what-counts-rd-qa.

Figure 10

Number of Companies in Global Fortune 500

Source: "Global 500," *Fortune,* https://fortune.com/global500/.

surpassed the European Union in 2015 in overall R&D investment, having allocated about $400 billion (with PPP correction) in 2015.[41] As shown in Figure 1, the U.S. National Science Board has estimated that China's spending on R&D at PPP equaled that of the United States sometime in 2018 or soon thereafter.

A LOOMING THREAT

Approaching in the not-too-distant future is a fiscal circumstance that could greatly complicate any plans for increased R&D funding in the United States. This near-existential issue has received little attention from those addressing the nation's future investments in R&D.

The issue has been noted by the Congressional Budget Office (CBO) for several years, but with seemingly little impact. As illustrated in Figure 12, expenditures already committed under current law for only two general budgetary categories – entitlements and debt interest – are projected to equal the totality of federal revenues by 2042. At that time any R&D funding will have to compete directly with such priorities as national defense, homeland security, and infrastructure. Major elements of entitlement (nondiscretionary) outlays are Social Security, Medicare, Medicaid, and pension obligations – each exceedingly difficult to reduce, at least from a political standpoint. If the tax reductions enacted by the Tax Cuts and Jobs Act of 2017 are extended beyond their scheduled expiration in 2025, revenues will be further reduced. Similarly, if interest rates rise above currently projected levels (about 1.5 percent over the next ten years), outlays will further increase. The most recent CBO projection, assuming rapid economic recovery from COVID-19, is that federal spending in 2030 will reach 23 percent of GDP, while revenues equal 17.8 percent of GDP.

The U.S. national debt is now over $23 trillion, while its GDP is nearly $22 trillion. The federal debt held by the public (as opposed to debt held by government accounts or intragovernmental debt) equals 73 percent of that total. Prospects for reducing debt, given recent history, must be considered tenuous at best.

41. "R&D Expenditure," Eurostat: Statistics Explained, last modified September 2019, https://ec.europa.eu/eurostat/statistics-explained/index.php/R_%26_D_expenditure.

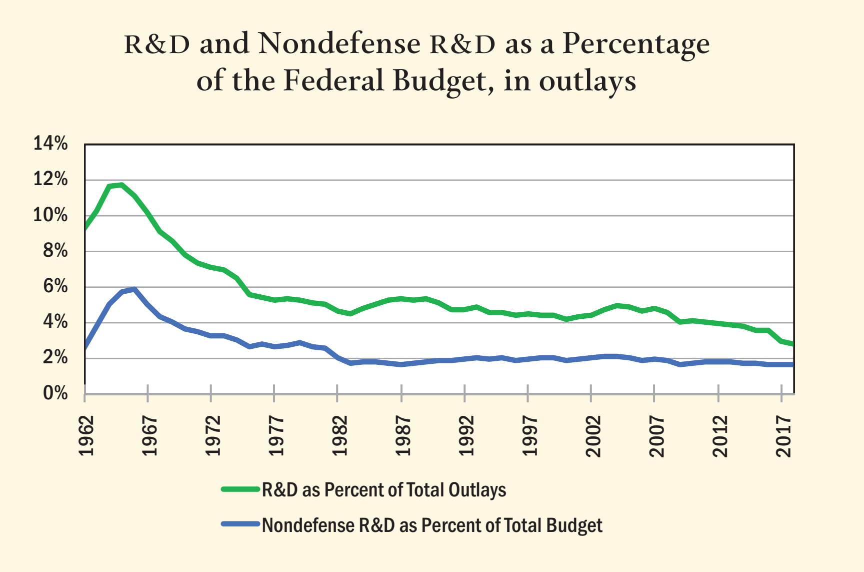

Figure 11

R&D and Nondefense R&D as a Percentage of the Federal Budget, in outlays

Source: American Association for the Advancement of Science, "Historical Trends in Federal R&D," 2019, https://www.aaas.org/programs/r-d-budget-and-policy/historical-trends-federal-rd.

During fiscal year 2019 alone the national debt increased by nearly 6 percent, driven by a deficit increase of 26 percent. Should the economic decline due to the pandemic linger for an extended time, this dilemma will intensify.

Even under the most favorable conditions, R&D will be increasingly squeezed as it competes for a portion of the vanishing discretionary element of the federal budget – absent large increases in taxes or borrowing or major reductions in entitlements. These observations highlight the need to establish a national understanding of the importance of research and the impact it has on the standard of living of Americans.

THE PERILS OF COMPLACENCY

Some observers, not unreasonably, ask why the government should fund R&D, particularly when industrial firms (and their stockholders, customers, and employees) are significant beneficiaries. In fact, industry now funds about two-thirds of the nation's R&D and the government funds nearly one-fourth – a complete reversal of shares since the mid-1960s. Accompanying this shift, however, has been a transition in industry investment practice, wherein the highest priority is placed on D (development) rather than R (research). As a result, most of America's great corporate research institutions have declined or been shuttered. The canonical example, Bell Laboratories, the home of nine Nobel Prizes and 15 Nobel laureates, along with the laser and transistor, is now owned by the Finnish company Nokia.[42] Overall support for basic research, which has the potential to be the most transformative research in the long term, has suffered in the United States and is now much more dependent on government or other (nonbusiness) sources of funding such as private philanthropy.

With regard to the translation of research results into marketable products and services, the United States has benefited from a robust private equity market that has made very substantial amounts of capital available to start-up firms. Venture capital investment in U.S. companies was estimated to be over $100 billion in 2018 alone.[43] However, the financial markets upon which innovators depend for resources are also increasingly seeking near-term returns. In the case of corporate equity, shareholders now hold their shares for only about four months rather than the eight years of a few decades ago.[44] In the case of day traders and arbitrageurs, the holding period can frequently be measured in nanoseconds.[45] In such an environment, the government becomes the funder of only resort, the default funder for long-term, high-risk/high-payoff

42. "Global Recognition for Groundbreaking Discovery," Nokia Bell Labs, https://www.bell-labs.com/about/recognition/.

43. Kate Clark, "Venture capital investment in US companies to hit $100B in 2018," *TechCrunch*, October 9, 2018, https://techcrunch.com/2018/10/09/venture-capital-investment-in-us-companies-to-hit-100b-in-2018/.

44. "Stocks For Rent: Holding Periods At 60-Year Lows," First Fiduciary, https://www.firstfiduciary.com/newsletter/2017/12/19/stocks-for-rent-holding-periods-at-60-year-lows.

45. John Markoff, "Time Split to the Nanosecond Is Precisely What Wall Street Wants," *New York Times*, June 29, 2018, https://www.nytimes.com/2018/06/29/technology/computer-networks-speed-nasdaq.html.

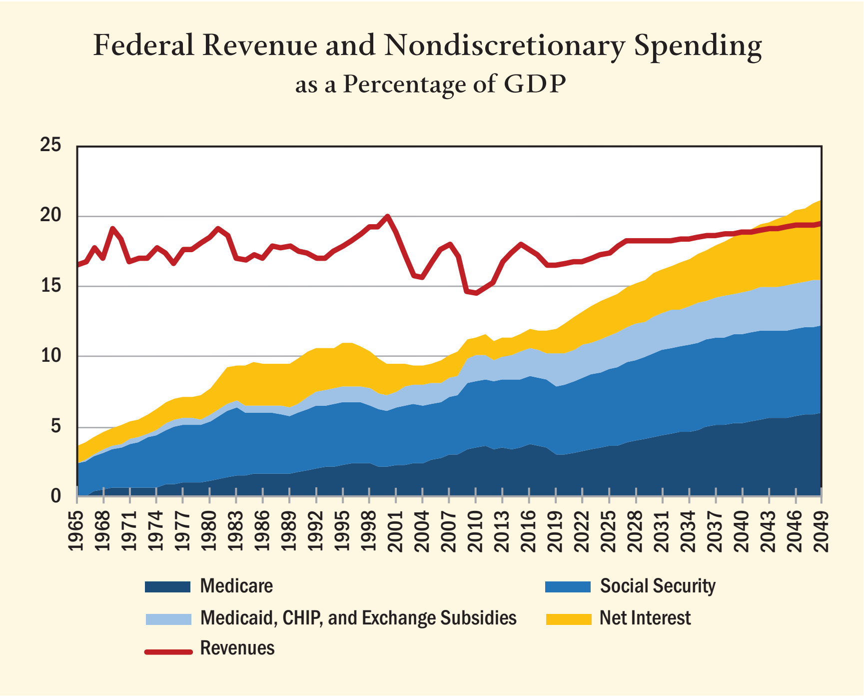

Figure 12

Federal Revenue and Nondiscretionary Spending as a Percentage of GDP

Source: Congressional Budget Office, https://www.cbo.gov/about/products/budget-economic-data, accessed January 23, 2020.

endeavors – such as basic research – that serve the citizenry as a whole but do not necessarily immediately reward the investor or researcher.

China has addressed this issue by establishing sizable government funds to support innovation and making substantial investments in promising American firms that have been unable to obtain domestic funding. In the first half of 2018, China, for the first time, raised more money for venture capital than America.[46] China is investing tens of billions of dollars in arguably the most important enabling element of the ongoing technological revolution, the semiconductor integrated circuit, through the recent establishment of its Integrated Circuit Investment Fund.[47]

China is, of course, not without its internal challenges. These include large groups of restive citizens in several areas of the country, including dissent in Hong Kong, backlash over constraints on everyday life, gender imbalance, COVID-19, an aging population, an environmental crisis, and slowing economic growth. But the nation's performance over recent decades in innovation through science and technology cannot be denied, and the Chinese government has given no indication that it plans to alter its growth strategy for R&D. In fact, it continues to publicly state its intentions of dominance – and is providing the funds to achieve it. For the United States to embrace an R&D investment strategy that depends on China imploding seems fanciful at best.

The competitive position of the United States in the world is thus poised to shift rapidly in the next several years. Given the enormous scale and rate of progress of Asia, particularly China, the United States will find that reversing its own downward slide will be very difficult. In the world of R&D and innovation, change occurs rapidly. As but one example, Apple's omnipresent iPhone (the quintessential smartphone) has been on the market for only 13 years.

Developments at home and abroad have placed the United States at a precarious "tipping point" regarding its future global competitiveness. America's

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46. https://www.scmp.com/tech/article/2153798/china-surpasses-north-america-attracting-venture-capital-funding-first-time.

47. Li Tao, "How China's 'Big Fund' Is Helping the Country Catch Up in the Global Semiconductor Race," *South China Morning Post*, May 10, 2018, https://www.scmp.com/tech/enterprises/article/2145422/how-chinas-big-fund-helping-country-catch-global-semiconductor-race.

creation of jobs, its healthcare, national security, and overall quality of life may well hang in the balance. And, with the increased attention being paid to science and technology and rapid growth in R&D funding in other countries, especially China, the urgency is increasing for the United States to respond . . . and respond decisively. The future of the nation depends on taking action to assure a vibrant and productive R&D enterprise. If we ignore this issue, declines in the economic well-being of our citizenry and our ability to influence world affairs will be inevitable.

RECOMMENDATIONS

Reaffirming the 2014 Recommendations

The committee reasserts the prescriptions and implementing actions offered in the American Academy's 2014 *Restoring the Foundation* report (see Appendix, page 45). To account for events that have transpired over the past five years, the committee urges that particular attention be devoted to the following recommendations:

- The nation should increase total R&D investment (public and private) as a fraction of GDP from 2.7 percent to 3.0 percent within five years and to at least 3.3 percent within ten years [**RtF1 Action 1.1**].
  - Several recent U.S. presidents have called for significant increases in funding for R&D, including Presidents Ronald Reagan,[48] Bill Clinton,[49] George W. Bush, and Barack Obama.[50] In 2009, President Obama stated that total national R&D investment should surpass 3

48. "President Reagan on Basic Research," *FYI: Science Policy News from AIP*, no. 102 (August 26, 2011), https://www.aip.org/fyi/2011/president-reagan-basic-research.

49. Rex Dalton, "Clinton Proposes $2.8 Billion Increase in Science Funding," *Nature* 403 (2000): 349, https://doi.org/10.1038/35000362.

50. George W. Bush, "American Competitiveness Initiative: President's Letter," February 2, 2006, https://georgewbush-whitehouse.archives.gov/stateoftheunion/2006/aci/index.html.

percent of GDP.[51] R&D investment, however, has continued to vary between 2.4 and 2.7 percent for over 30 years. Given the impact of R&D on the nation's economy, national security, and the accelerating global competition, the R&D target should be increased to at least 3.3 percent, a figure more competitive with leading countries.

- Federal funding for basic research should be increased at a sustained real growth rate of at least 4 percent per year, with the goal of raising federal basic research funding as a percentage of GDP by 50 percent from the present 0.2 percent to 0.3 percent [RtF1 Action 1.1].
  - Basic research in STEM fields – especially research funded by the federal government – will undoubtedly continue to yield major discoveries that revolutionize technology and fuel innovation. But increases in basic research funding should not come at the expense of applied research. Ideally, investments in the latter would increase at about the same rate. Of course, the boundary between basic and applied research in many fields is not sharp.
- The White House Office of Science and Technology Policy (OSTP), in cooperation with the Office of Management and Budget (OMB) and government funding agencies, should prepare a rolling five-year integrated federal R&D funding plan for each of the agencies that support R&D, including overall funding targets for the three categories of basic research, applied research, and development [RtF1 Action 1.4].
  - Each federal agency plans its allocation of funds for R&D in the context of its unique mission. But an overall federal strategy for supporting the priority areas of science and engineering requires planning across government. The role of OSTP in the annual budget process is advisory, but OSTP works closely with OMB on the parts of the president's budget that relate to science and technology. The cabinet-level National Science and Technology Council, which includes the directors of OSTP and OMB, is a critical element in achieving the above goal.

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51. "Obama: 3% of GDP for R&D," *FYI: Science Policy News from AIP*, no. 49 (April 27, 2009), https://www.aip.org/fyi/2009/obama-3-gdp-rd.

- A capital budgeting process should be established to provide resources for federally funded R&D facilities [RtF1 Action 1.3].
    - Corporations and other institutions have many decades of experience that demonstrate the value of capital budgeting, based on evaluating the long-term impact of current investments. Multiyear budgeting for the construction and updating of large R&D facilities, including procurement of major research equipment, would avoid wasteful year-to-year fluctuations in agency appropriations.
- U.S. R&D budgets should be appropriated on (at least) a two-year cycle, rather than annually [RtF1 Action 1.2].
    - Quality research and development are not carried out in one-year segments. In particular, the agencies that support research can best serve the nation's interest in advancing scientific knowledge by having longer time horizons for making investments. Large year-to-year fluctuations in appropriations waste money and are inimical to the performance of quality research.
- The number of H1-B visas should be doubled and immediate family members of recipients appropriately accommodated [RtF1 Action 3.7].
    - The U.S. S&T enterprise will require additional talent. Much of that talent, at least in the decade ahead, will have to come from abroad as it has in the past. Young men and women throughout the world continue to be attracted to America's universities, and the United States should institute policies that encourage them to remain in America after receiving their education and thereby contribute as members of the U.S. STEM workforce.
- Regulations, policies, and reporting requirements currently imposed on the conduct of R&D should be reviewed with the purpose of eliminating constraints that do not offer demonstrable benefits [RtF1 Action 2.2a].
    - Over a period of decades, many well-meaning rules, regulations, and other polices have been put in place that reduce the productivity of the nation's researchers but have little or no benefit. Several well-researched reports have described these in detail and have

offered specific policy reforms.[52] Further studies are not needed; it is time for action by the federal agencies, the OMB, and, in some cases, Congress.

- As new policies are considered by the nation's universities and federal agencies to ensure the proper protection of intellectual property, while continuing to encourage foreign-born students and science and engineering researchers to study and establish careers in the United States, any new regulations should not place major administrative burdens on researchers and institutions.

- Universities should revise their policies on intellectual property to better reflect the original intent of the 1980 Bayh-Dole Act. The act was designed to help ensure that the public received the benefits of federally funded R&D by giving universities ownership of the intellectual property produced by their faculty and encouraging universities to share their discoveries and inventions with industry through patents and licensing agreements. Companies and universities should implement mechanisms that enable more effective partnerships and especially encourage transdisciplinary joint research. The federal government should clarify and, if necessary, revise tax laws to encourage stronger university-industry partnerships [**RtF1 Action 3.2**].[53]
    - Over many decades, laws, rules, and other policies and practices have accumulated that hinder university-industry partnerships and defer the potential to be far more powerful components of the nation's innovation and global competitive strategy.

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52. National Science Board, *Reducing Investigators' Administrative Workload for Federally Funded Research*, NSB-14-18 (Arlington, Va.: National Science Foundation, 2014), https://www.nsf.gov/pubs/2014/nsb1418/nsb1418.pdf; and National Academies of Sciences, Engineering, and Medicine, "Optimizing the Nation's Investment in Academic Research: A New Regulatory Framework for the 21st Century," https://www.nap.edu/catalog/21824/optimizing-the-nations-investment-in-academic-research-a-new-regulatory.

53. For additional recommendations, see *ARISE II–Advancing Research In Science and Engineering: The Role of Academia, Industry, and Government in the 21st Century* (Cambridge, Mass.: American Academy of Arts and Sciences, 2014), https://www.amacad.org/project/arise-ii-advancing-research-science-and-engineering-role-academia-industry-and-government.

New Recommendations for 2020

In addition to the recommendations originally made in the 2014 *Restoring the Foundation* report and reiterated above, which focused on R&D priorities, we append the following recommendations focused on strengthening U.S. STEM education and the American workforce:

- The recommendations in the 2005 National Academies of Sciences, Engineering, and Medicine's *Gathering Storm* report pertaining to pre-K-12 education should be implemented, including creating each year 10,000 federally funded four-year scholarships in STEM fields to be competitively awarded to U.S. citizens in exchange for a commitment to teach STEM in a public school for at least five years following graduation.
  - The nation's pre-K-12 public education system has been in crisis for decades, and the urgent need to improve student achievement was one of the seven priorities listed in the "Innovation: An American Imperative" call to action that was supported by over 500 organizations across the country.[54] The National Academies of Sciences, Engineering, and Medicine, in its *Gathering Storm* report, laid out a strategy to address the crisis.[55]
- States should return to, and then sustain or increase, pre-Great Recession levels of public university funding, as measured per full-time equivalent (FTE) student.
  - Restoring state funding for universities will enable those institutions to better serve the educational needs of the state's citizens, raise the skill level of the workforce; support full employment; form stronger partnerships with local companies; and contribute to the country's S&T enterprise and economy.

54. "Innovation: An American Imperative," http://www.innovationimperative.org.

55. National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, *Rising above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future* (Washington, D.C.: National Academies Press, 2007), https://doi.org/10.17226/11463.

- The recent tax placed on the earnings of endowments of (private) universities represents an altogether counterproductive trend and should be repealed promptly.
    - Repealing this punitive tax will help universities control tuition, provide more financial aid, and maintain modern research and teaching facilities. Doing so will also, hopefully, discourage further such narrowly targeted, counterproductive approaches.

* * *

The above recommendations are offered as an integrated package. For example, it would not make sense to significantly increase the number of researchers if the funds are not made available to support their research. America's future leadership in science, technology, and innovation will require both. Further, the committee is acutely aware of the budgetary constraints faced by the federal government and the trend toward growing deficits. Many of the committee's recommendations will require additional funding. But the committee does not accept the notion that, for example, the recommended additional 0.1 percent of GDP cannot be allocated to the federally funded basic research that is so vital to the health, security, and overall well-being of Americans.

The issue at hand is principally one of priority.

U.S. citizens currently enjoy a GDP per capita that is nearly six times that of the average of all other citizens on the planet. This is substantially a consequence of American ingenuity and past investments in R&D, higher education, innovation, and related domains. The declining position of the United States in science and technology has not occurred overnight, nor has it been imposed upon the United States by others. It is not China that restrained the nation's investment in R&D; that allows the continuing decay of our pre-K-12 education system; that reduced the number of foreign graduates from U.S. universities who can remain and work in America; or that disinvested in our public universities.

Decisions made, or not made, at this inflection point for America's competitiveness will determine whether we, unlike all prior generations of Americans, leave to our children and grandchildren a lower standard of living and fewer opportunities than we ourselves enjoyed. Will today's adult Americans one day be referred to as America's "Most Selfish Generations," treasuring consumption above investment?

A FINAL OBSERVATION

If the United States is to continue to be a leader in the increasingly competitive global markets that now characterize the 21st century, the pace of American innovation – translation of discoveries and inventions from laboratory research to products – will have to accelerate. That industry will focus its R&D investments on meeting relatively immediate challenges is understandable and makes it all the more important that the federal government accelerate its own investment in research, especially basic research in all fields of science, engineering, medicine, and mathematics, encouraging truly bold ideas and funding projects that have a low probability of obvious success at the time of funding but have the potential to be transformative in the long term. Lowering the barriers to industry-university collaboration will then make it much easier for those pathbreaking discoveries to move quickly into applications, including commercial products, markets, economic growth, and high-paying jobs.

To predict, with any confidence, what new capabilities science and technology will bring in the decades ahead is impossible. But to see how different our lives would be today without the contribution of science and technology in the past decades is not difficult: no smartphones, high-definition TV, laptops, electric and hybrid cars, magnetic resonance imaging, artificial joints, stents, laser eye surgery, or vaccines for diseases such as polio. Nor would the world have e-commerce, GPS in its cars, or cures for hepatitis C. Without advances in science and technology and private-sector innovation, the world will not develop cleaner methods of power generation, adapt to climate change, or conquer future diseases. And without advances in science, COVID-19 will not be conquered.

Not every scientific discovery or technological innovation will have its origin in the United States, nor does it need to do so. This makes international scientific cooperation vital to American interests. But unless the United States remains a leading contributor to the discovery of new knowledge and has the capacity and the will to translate that knowledge into applications, Americans and America will be left behind, isolated, and increasingly impoverished in a 21st-century world powered by science and technology. A great opportunity will have been lost.

The committee preparing this report has sought to balance, insofar as possible, the critical need for enhanced investment in research and development with the severe budgetary pressures that will be faced in the years ahead.

Appendix

Recommendations from *Restoring the Foundation*

Prescription 1

Secure America's Leadership in Science and Engineering Research – Especially Basic Research – by Providing Sustainable Federal Funding and Setting Long-Term Investment Goals

ACTION 1.1 – We recommend that the President and Congress work together to establish a sustainable real growth rate of *at least* 4 percent in the federal investment in basic research, approximating the average growth rate sustained between 1975 and 1992 (see Figure 13). This growth rate would be compatible with a target of at least 0.3 percent of GDP for federally supported basic research by 2032 (one-tenth the national goal for combined public and private R&D investment adopted by several U.S. presidents). We stress that an increase in support for basic research should not come at the expense of investments in applied research or development, both of which will remain essential for fully realizing the societal benefits of scientific discoveries and new technologies that emerge from basic research.

We further recommend that, as the U.S. economy improves, the federal government strive to exceed this growth rate in basic research, with the goal of returning to the sustainable growth path for basic research established between 1975 and 1992.

Productive first steps include:

- Establishment of an aggressive goal of *at least* 3.3 percent GDP for the total national R&D investment (by all sources) and a national discussion of the means of attaining that goal;

- Strong reauthorization bills, following the model set by the 2007 and 2010 America COMPETES Acts,[56] that authorize the investments necessary to renew America's commitment to science and engineering research and STEM education and reinforce the use of expert peer review in determining the scientific merit of competitive research proposals in all fields;
- Appropriations necessary to realize the promise of strong authorization acts; and
- A "Sense of the Congress" resolution affirming the importance of these goals as a high-priority investment in America's future.

ACTION 1.2 – We recommend that the President and Congress adopt *multi-year appropriations* for agencies (or parts of agencies) that primarily support research and graduate STEM education. Providing research agencies with advanced notice of pending budgetary changes would allow them to adjust their grant portfolios and the construction of new facilities accordingly. The resulting efficiency gains would reduce costs while enhancing research productivity.

ACTION 1.3 – We recommend that the White House Office of Management and Budget (OMB) establish a *strategic capital budget process* for funding major research instrumentation and facilities, ideally in the context of a broader national capital budget that supports investment in the nation's infrastructure; and that enabling legislation specifically preclude earmarks or other mechanisms that circumvent merit review.

ACTION 1.4 – We recommend that the President include in the annual budget request to Congress a rolling long-term (five-to-ten-year) plan for the allocation of federal R&D investments – especially funding for major instrumentation that requires many years to plan and build.

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56. *America COMPETES Act*, Public Law 110-69, H.R. 2272, 110th Congress (January 4, 2007); and *America COMPETES Reauthorization Act of 2010*, Public Law 111-358, H.R. 5116, 111th Congress (January 4, 2011).

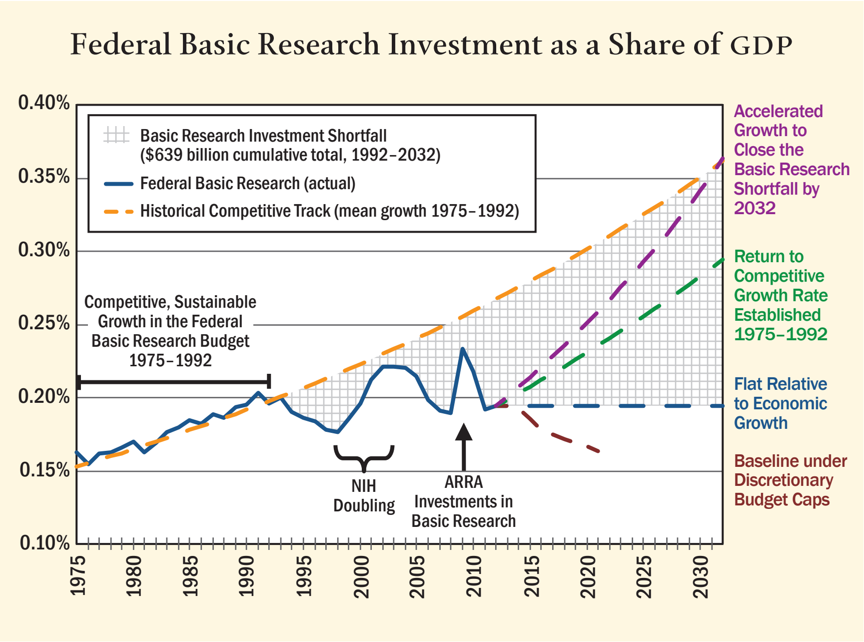

Figure 13

Getting U.S. Basic Research Back on Track

Should federal obligations for basic research (blue) flatline relative to economic growth, the United States will by 2032 have accumulated a $639 billion shortfall (cross-hatch) in federal support of basic research relative to the 4.4 percent average annual real growth trend (orange) established during the period of 1975 to 1992. This committee recommends that the nation return to this historical competitive growth rate (green), with the ultimate goal of fully closing the basic research shortfall (purple) as the economy improves.

Data Sources: Federal obligations for basic research from 1975 to 2012 are from the National Science Board, *Science and Engineering Indicators 2014* (Arlington, Va.: National Science Foundation, 2014), Appendix Table 4-34, "Federal Obligations for R&D and R&D Plant, by Character of Work: FYs 1953–2012." Basic research funding baseline projections are based on the nondefense discretionary funding levels from Office of Management and Budget, *Fiscal Year 2015 Budget of the U.S. Government* (Washington, D.C.: Office of Management and Budget, 2014), Table S-10, "Funding Levels for Appropriated ('Discretionary') Programs by Category," whose baseline levels assume Joint Committee enforcement cap reductions are in effect through 2021. GDP projections assume an average real annual growth rate of 2.2 percent until 2020 and 2.3 percent from 2020 to 2030, according to Jean Chateau, Cuauhtemoc Rebolledo, and Rob Dellink, "An Economic Projection to 2050: The OECD 'ENV-Linkages' Model Baseline," *OECD Environment Working Papers*, No. 41 (Paris: OECD Publishing, 2011), Table 4, https://doi.org/10.1787/5kgondkjvfhf-en.

Prescription 2

Ensure that the American People Receive the Maximum Benefit from Federal Investments in Research

ACTION 2.1 – We recommend that the President publish a biennial "State of American Science, Engineering & Technology" report giving the administration's perspective on issues such as those addressed by the *Science and Engineering Indicators* and related reports published by the National Science Foundation (NSF) National Science Board (NSB),[57] and with input from the federal agencies that sit on the President's National Science and Technology Council (NSTC). The report, if released with the President's budget, would provide information useful for both the appropriations and authorization legislative processes.

ACTION 2.2 – We recommend the following actions to enhance the productivity of America's researchers, particularly those based at universities:

> ACTION 2.2a – We recommend that the White House Office of Science and Technology Policy and Office of Management and Budget lead an effort to streamline or eliminate practices and regulations governing federally funded research that have become burdensome and add to the universities' administrative overhead while failing to yield appreciable benefits.
>
> ACTION 2.2b – We recommend that universities adopt "best practices" targeted at capital planning, cost-containment efforts, and resource sharing with outside parties, such as those described in the 2012 National

57. The statutory authority of the NSB is included under U.S. Code 42, Chapter 16, Paragraph 1863, http://www.law.cornell.edu/uscode/text/42/chapter-16: "Report to President; submittal to Congress: (1) The Board shall render to the President and the Congress no later than January 15 of each even numbered year, a report on indicators of the state of science and engineering in the United States; (2) The Board shall render to the President and the Congress reports on specific, individual policy matters within the authority of the Foundation (or otherwise as requested by the Congress or the President) related to science and engineering and education in science and engineering, as the Board, the President, or the Congress determines the need for such reports."

Research Council (NRC) report *Research Universities and the Future of America*.[58]

ACTION 2.2c – We recommend that universities and the National Institutes of Health (NIH) gradually adopt practices to foster an appropriately sized and sustainable biomedical research workforce.[59] Key goals should include reducing the length of graduate school and postdoctoral training and shifting support for education to training grants and fellowships; providing funding for master's degree programs that may provide more appropriate training for some segments of the biomedical workforce now populated by Ph.D.s; enhancing the role of staff scientists in university laboratories and core facilities; reducing the percentage of faculty salaries supported solely by grants; and securing a renewed commitment from senior scientists to serve on review boards and study sections.

ACTION 2.2d – We recommend that the President and Congress reaffirm the principle that competitive expert peer review is the best way to ensure excellence. Hence, peer review should remain the mechanism by which federal agencies make research award decisions, and review processes and criteria should be left to the discretion of the agencies themselves. In the case of basic research, scientific merit – based on the opinions of experts in the field – should remain the primary consideration for awarding support.

ACTION 2.2e – We recommend that the research funding agencies intensify their efforts to reduce the time that researchers spend writing and reviewing proposals, such as by expanding the use of pre-proposals, providing additional feedback from program officers, allowing authors to respond to reviewers' comments, further normalizing procedures

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58. National Research Council, *Research Universities and the Future of America: Ten Breakthrough Actions Vital to Our Nation's Prosperity and Security* (Washington, D.C.: The National Academies Press, 2012).

59. While the situation is particularly acute for the biomedical research workforce, mismatches between supply and demand also exist in other fields, such as computer science. Therefore, other federal agencies might also examine how their programs and priorities affect the workforce.

across the federal government, and experimenting with new approaches to streamline the grant process.

ACTION 2.3 – We recommend that the National Academies, the American Association for the Advancement of Science, and the American Academy of Arts and Sciences convene a series of meetings of nongovernmental organizations and professional societies that focus on science and engineering research, for the purpose of establishing a formal task force, alliance, or new organization to:

- Develop a common message about the nature and importance of science and engineering research that could be disseminated by all interested organizations;
- Elevate science and technology issues in the minds of the American public, business community, and political figures, and restore appropriate public trust;
- Ensure that the recommendations offered by existing science and technology policy organizations, academies, and other advisory bodies remain current and available to institutional leaders and policymakers in all sectors;
- Cooperate with organizations that are focused on business and commerce, national and domestic security, education and workforce, health and safety, energy and environment, culture and the arts, entertainment, and other societal interests and needs to encourage a discussion of the role of science, engineering, and technology in society; and
- Offer assistance – in real time – to federal and state government, universities, private foundations, and leaders in business and industry to help with implementation of policy reforms.

ACTION 2.4 – In order to have direct access to current information and analysis of important science and technology policy issues, we urge Congress to: 1) significantly expand the science, engineering, and technology assessment capabilities of the Government Accountability Office (GAO), including the size of the technical staff, or alternatively to establish and fund a new organization for that purpose; and 2) explore ways to tap the expertise of American researchers in a timely and non-conflicted manner. In particular, consideration should be given to ways in which either the GAO or another organization with scientific and technical expertise could use crowdsourcing and participatory technology assessment to rapidly collect research, data, and analysis related to specific scientific issues.

Prescription 3

Regain America's Standing as an Innovation Leader by Establishing a More Robust National Government-University-Industry Research Partnership

ACTION 3.1 – We recommend that the President or Vice President convene a "Summit on the Future of America's Research Enterprise" with participation from all government, university, and industry sectors and the philanthropic community. The Summit should have the bold action agenda to: assess the current state of science and engineering research in the United States in a global twenty-first-century context; review successful approaches to bringing each sector into closer collaboration; determine where further actions are needed to encourage collaboration; and form a new compact to ensure that the United States remains a leader in science, engineering, technology, and medicine in the coming decades.

ACTION 3.2 – We recommend that the nation's research universities:

- Experiment with new intellectual property policies and practices that favor the creation of stronger research partnerships with companies over the maximization of revenues;
- Adopt innovative models for technology transfer that can better support the universities' mission to produce and export new knowledge and educate students;
- Enhance early exposure of graduate students (including doctoral students) to a broad range of non-research career options in business, industry, government, and other sectors, and ensure that they have the necessary skills to be successful;

- Expand professional master's degree programs in science and engineering, with particular attention to students interested in non-research career options; and
- Increase permeability across sectors through research collaborations and faculty research leaves.

ACTION 3.3 – We recommend that the President and Congress, in consultation with leaders of the nation's research universities and corporations, consider legislation to remove lingering barriers to university-industry research cooperation, and specifically:

- Help universities overcome impediments to experimenting with new technology transfer policies and procedures that emphasize objectives (such as the creation of new companies and jobs), outcomes, and best practices (such as processes that minimize the time and cost of licensing); and
- Amend the U.S. tax code to encourage closer university-industry cooperation. For example, in the case of industry-funded research conducted in university buildings financed with tax-exempt bonds, the tax code should be amended to allow universities to enter into advance licensing agreements with industry.

ACTION 3.4 – We recommend that the federal agencies that operate or provide major funding for national laboratories[60] review their current missions, management, and operations, including the effectiveness of collaborations with universities and industry, and phase in changes as appropriate. While consultation with these laboratories is critical in carrying out such reviews, the burden of reviews and other agency requirements is already heavy and should, over time, be reduced.

ACTION 3.5 – We recommend that corporate boards and chief executives give higher priority to funding research in universities and work with university

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60. As used here, *national laboratories* include intramural laboratories and centers at the Department of Energy (DOE), Department of Defense (DOD), National Oceanic and Atmospheric Administration (NOAA), National Aeronautics and Space Administration (NASA), National Institute of Standards and Technology (NIST), United States Department of Agriculture (USDA), and the National Institutes of Health (NIH).

presidents and boards to develop new forms of partnership: collaborations that can justify increased company investments in university research, especially basic research projects that provide new concepts for translation to application and are best suited for training the next generation of scientists and engineers.

ACTION 3.6 – We strongly urge Congress to make the Research and Experimentation (R&E) Tax Credit permanent, as recommended by the President's Council of Advisors on Science and Technology (PCAST), the National Academies, the Business Roundtable, and many others. Doing so would provide an incentive for industry to invest in long-term research in the United States, including collaborative research with universities such as that recommended under Action 3.5.

ACTION 3.7 – We support the recommendation made by many other organizations, including the President's Council of Advisors on Science and Technology and the National Academies,[61] both to increase the number of H-1B visas and to reshape policies affecting foreign-born researchers in order to attract and retain the best and brightest researchers. Productive steps include allowing foreign students who receive a graduate degree in STEM disciplines from a U.S. university to receive a green card (perhaps contingent on receiving a job offer) and stipulating that each employment-based visa automatically covers a worker's spouse and children.

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61. See President's Council of Advisors on Science and Technology, *Transformation and Opportunity: The Future of the U.S. Research Enterprise* (Washington, D.C.: Executive Office of the President of the United States, 2012); Institute of Medicine, National Academy of Sciences, and National Academy of Engineering, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future* (Washington, D.C.: The National Academies Press, 2007); and National Research Council, *Research Universities and the Future of America*.

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