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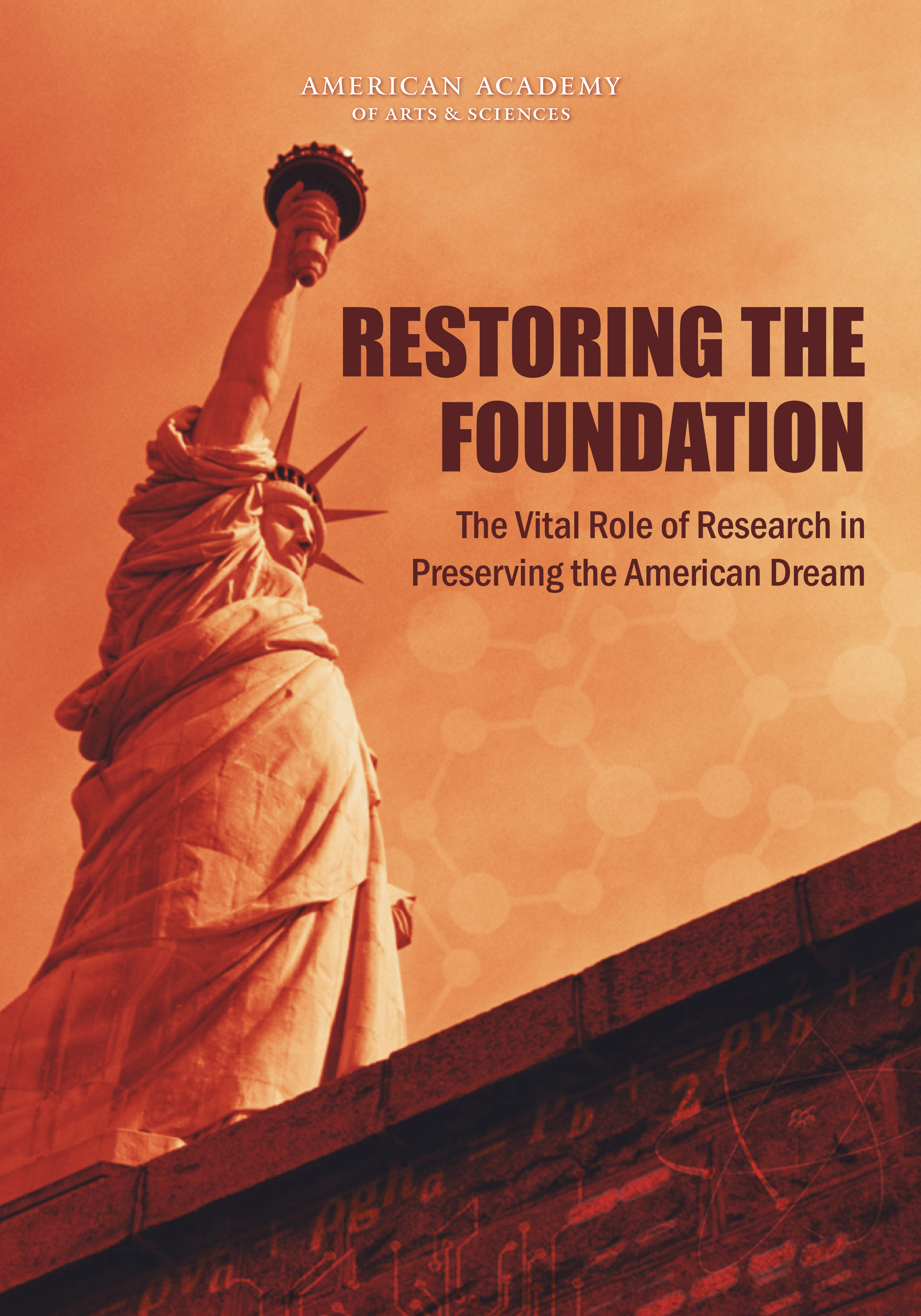
The Vital Role of Research in Preserving the American Dream



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The Vital Role of Research in Preserving the American Dream

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The American Academy dedicates this report to the memory of Charles M. Vest, one of America's leading advocates for science, engineering, and higher education. Among his many contributions, Dr. Vest served as Cochair of the Academy's oversight committee on Science, Engineering & Technology. His life embodied the American Dream, and his quiet wisdom, vision, and commitment to national service continue to inspire the Academy's work.

American Academy of Arts & Sciences

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Norman R. Augustine (Lockheed Martin Corporation, *ret.*)

Neal F. Lane (Rice University)

Acronym Guide (in alphabetical order)

A*STAR – Agency for Science, Technology and Research (Singapore)
AAAS – American Association for the Advancement of Science
ACI – American Competitiveness Initiative
AEC – Atomic Energy Commission
ARPA – Advanced Research Projects Agency
ARPA-E – Advanced Research Projects Agency – Energy
ARRA – American Recovery and Reinvestment Act of 2009
AUTM – Association of University Technology Managers
BEST – Broadening Experiences in Scientific Training
BRAIN Initiative – Brain Research through Advancing Innovative Neurotechnologies Initiative
CERN – European Organization for Nuclear Research
CCD – Charge-Coupled Device
CIRM – California Institute for Regenerative Medicine
CRS – Congressional Research Service
DARPA – Defense Advanced Research Projects Agency
DOC – Department of Commerce
DOD – Department of Defense
DOE – Department of Energy
DOEd – Department of Education
DSAR – Division of Statistical Analysis & Reporting
EPA – Environmental Protection Agency
EPSCoR – Experimental Program to Stimulate Competitive Research
ERDA – Energy Research and Development Administration
ESA – European Space Agency
F&A – Facilities and Administrative
FFRDCs – Federally Funded R&D Centers
GAO – Government Accountability Office
GDP – Gross Domestic Product
GI – Government-Industry
GPS – Global Positioning Systems
GU – Government-University
GUI – Government-University-Industry
HHMI – Howard Hughes Medical Institute
HST – Hubble Space Telescope
IP – Intellectual Property
ISS – International Space Station
IT – Information Technology
ITRI – Industrial Technology Research Institute (of Taiwan)
KTI – Knowledge- and Technology-Intensive

LHC – Large Hadron Collider
LSFSS – Longitudinal Study of Future STEM Scholars
LSM – Life Sciences and Medicine
MEP – Manufacturing Extension Partnership
MN-IP – University of Minnesota's Minnesota Innovation Partnerships
NASA – National Aeronautics and Space Administration
NCHGR – National Center for Human Genome Research
NCI – National Cancer Institute
NDEA – National Defense Education Act
NGO – Nongovernmental Organization
NHGRI – National Human Genome Research Institute
NIH – National Institutes of Health
NIST – National Institute of Standards and Technology
NNI – National Nanotechnology Initiative
NOAA – National Oceanic and Atmospheric Administration
NRC – National Research Council
NRF – Nation Research Foundation
NSB – National Science Board (of the NSF)
NSF – National Science Foundation
NSTC – (The President's) National Science and Technology Council
NYSTEM – New York State Stem Cell Science
OECD – Organisation for Economic Co-operation and Development
OER – Office of Extramural Research
OMB – Office of Management and Budget
ONR – Office of Naval Research
OPAC – Office of Planning, Analysis, and Communications
OSRD – Office of Scientific Research and Development
OSTP – Office of Science and Technology Policy
OTA – Office of Technology Assessment
OTL – Office of Technology Licensing
PCAST – President's Council of Advisors on Science and Technology
PECASE – Presidential Early Career Award for Scientists and Engineers
PI – Principal Investigator
PSAC – President's Science Advisory Committee
PSE – Physical Sciences and Engineering
PSM – Professional Science Master's (degree)
R&D – Research and Development
R&E – Research and Experimentation
RePORT – Research Portfolio Online Reporting Tools

SBIR – Small Business Innovation Research
SE&T – Science, Engineering, and Technology
STARTUP-NY – SUNY Tax-free Areas to Revitalize and Transform Upstate New York
STEM – Science, Technology, Engineering, and Mathematics
STS – Space Transportation System
TIP – Technology Innovation Program
TTO – Technology Transfer Offices
UI – University-Industry
USDA – United States Department of Agriculture
VA – Department of Veterans Affairs

NOTE ABOUT USAGE: Throughout the report, when referring to *research*, we have used the phrase "science and engineering research." When referring to *education*, we have used the phrase "STEM education." And when referring to *policy*, we have used the phrase "science and technology policy."

Executive Summary

"Industry's nearly total R&D focus on rapidly commercializing products, when combined with growing constraints on support of university research, could devastate our national innovation system. It could well leave us without a shared, evolving base of new scientific knowledge and new technology. ***It could destroy the primary source of tomorrow's products, jobs, and health.***

Many Americans have long been concerned that we [are] mortgaging our children's future with ever-increasing federal budget deficits. Rightly so. ***We must not, however, foreclose on their future by failing to invest in their education and in the research that will be the basis of their progress."***

– Charles M. Vest, July 18, 1995, in a speech delivered to the National Press Club[1]

The American research enterprise is at a critical inflection point. The decisions that policy-makers and leaders in science, engineering, and technology make over the next few years will determine the trajectory of American innovation for many years to come.

Recent data show that the United States has slipped to tenth place among OECD (Organisation for Economic Co-operation and Development) nations in overall research and development (R&D) investment as a percentage of GDP (gross domestic product),[2] and continues to fall short of the goal of at least 3 percent adopted by several U.S. presidents (see Figure 1, pages 9–10). As we lose our global competitive edge, many emerging nations are increasing their research investments in order to stimulate economic growth. Indeed, China is projected to outspend the United States in R&D within the next ten years, both in absolute terms and as a fraction of economic output.[3] If our nation does not act quickly to shore up its scientific enterprise, it will squander the advantage it has long held as an engine of innovation that generates new discoveries and stimulates job growth.

Innovation relies on breakthrough discoveries that are primarily the products of fundamental, curiosity-driven research. Yet companies – finding it increasingly difficult to justify such long-term investments in a market environment focused on short-term results – have made it clear

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1. Charles M. Vest, "In Search of Mediocrity: Is America Losing its Will To Excel?" speech delivered to the National Press Club, Washington, D.C., July 18, 1995, http://web.mit.edu/president/communications/NPC-7-95.html.

2. Organisation for Economic Co-operation and Development, *Main Science and Technology Indicators*, vol. 2013, no. 2 (Paris: OECD Publishing, 2014), Table 2, "Gross Domestic Expenditures on R&D (GERD) as a Percentage of GDP."

3. Battelle and *R&D Magazine*, *2014 Global R&D Funding Forecast* (December 2013).

that the federal government must continue to be the primary funder of basic research. It is therefore worrisome that federal support for basic research has dropped 13 percent below the level measured ten years ago as a percentage of GDP.

Budgetary pressures are only expected to increase. Current budget projections predict that discretionary spending – of which basic research investments are a small percentage – will shrink from 35 percent to 23 percent of the federal budget over the next ten years.[4] Unless basic research becomes a higher government priority than it has been in recent decades, the potential for fundamental scientific breakthroughs and future technological advances will be severely constrained.

Compounding this problem, few mechanisms currently exist at the federal level to enable policy-makers and the research community to set long-term priorities in science and engineering research, bring about necessary reforms of policies that impede progress, or facilitate stronger cooperation among the many funders and performers of research (including universities, corporations, federal and state government, and philanthropic and nongovernmental organizations).

In response to these concerns, the American Academy of Arts & Sciences assembled a committee of recognized leaders from all sectors of science, engineering, and technology, including former CEOs, university presidents and deans, and government officials, to recommend policy actions to help ensure the long-term sustainability of the U.S. science and engineering research enterprise. The committee based its work on three premises: first, that a strong U.S. economy is vital to the welfare and prosperity of the American people; second, that competitiveness in today's accelerating high-tech, knowledge-based economy requires innovation and the rapid infusion of new knowledge and technologies; and third, that while applied research and applied development are both undeniably important, pathbreaking discoveries are most likely to come from basic research sustained over long periods of time, which is mainly funded by the federal government and carried out in the nation's universities and national laboratories.

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4. Between FY 2013 and FY 2024, the Congressional Budget Office projects that mandatory spending will increase by 80 percent (from $2.032 trillion to $3.664 trillion) while discretionary spending will increase by 15 percent (from $1.202 trillion to $1.380 trillion), resulting in an overall decrease in discretionary spending as a share of the total federal budget. See Congressional Budget Office, *Updated Budget Projections: 2014 to 2024* (Washington, D.C.: Congressional Budget Office, 2014), Table 1, "CBO's Baseline Budget Projections."

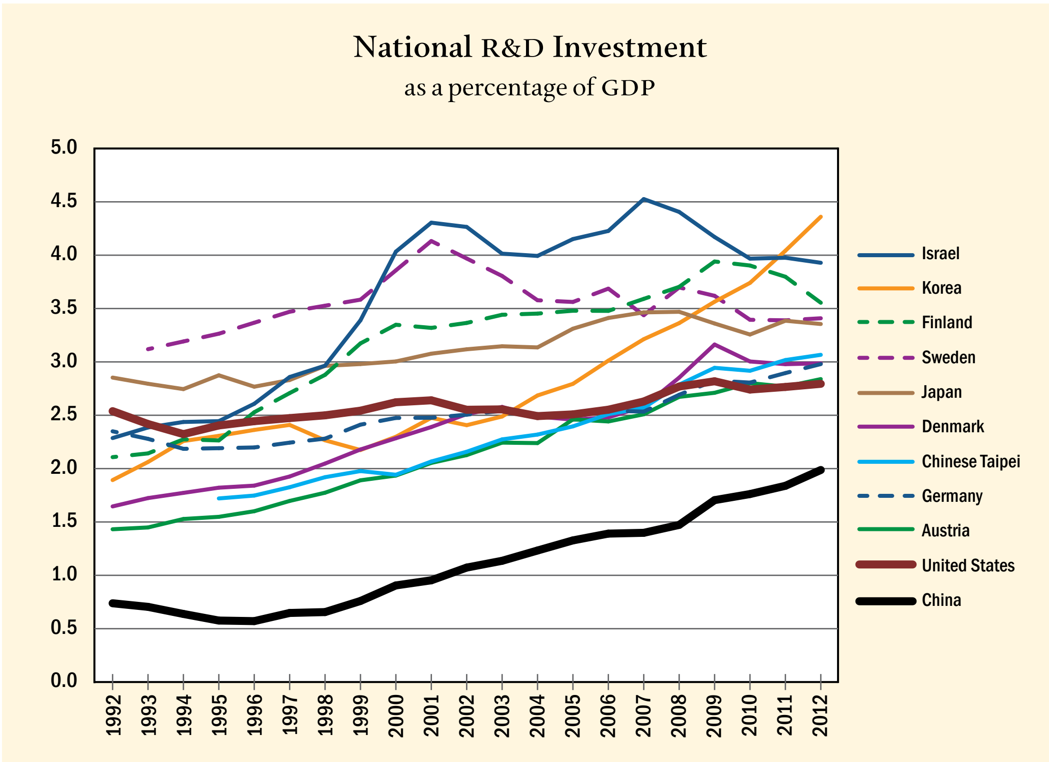

Figure 1A

The United States is Failing to Keep Pace with Competitors' Investments in R&D

As China's R&D intensity (black) rapidly grows by an average of 8 percent per year in pursuit of the goal of R&D investment equal to 3 percent of GDP, U.S. investments (red) have pulled back. At this pace, China will surpass the United States in R&D intensity in about eight years.[5]

Source: Organisation for Economic Co-operation and Development, *Main Science and Technology Indicators*, vol. 2013, no. 2 (Paris: OECD Publishing, 2014), Table 2, "Gross Domestic Expenditures on R&D (GERD) as a Percentage of GDP."

5. Ibid.

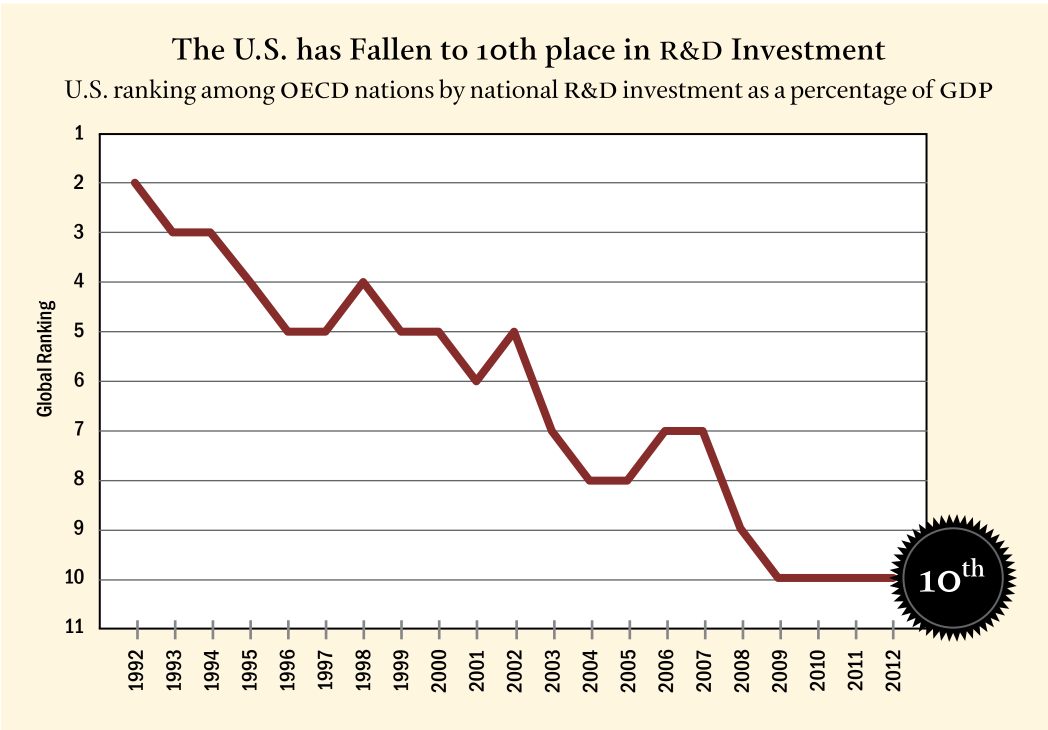

Figure 1B

The United States is Failing to Keep Pace with Competitors' Investments in R&D

Among OECD nations, the United States ranks tenth in R&D intensity (national R&D investment as a percentage of GDP).

Source: Organisation for Economic Co-operation and Development, *Main Science and Technology Indicators*, vol. 2013, no. 2 (Paris: OECD Publishing, 2014), Table 2, "Gross Domestic Expenditures on R&D (GERD) as a Percentage of GDP."

The committee's recommendations focus on three overarching objectives:

> First, to *secure America's leadership in science and engineering research – especially basic research – by providing sustainable federal investments*.
>
> Second, to *ensure that the American people receive the maximum benefit from federal investments in research*.
>
> Third, to *regain America's standing as an innovation leader by establishing a more robust national government-university-industry research partnership*.

America's economic ascendency in the twentieth century was due in large part – perhaps even primarily – to its investments in science and engineering research. Basic research lies behind every new product brought to market, every new medical device or drug, every new defense and space technology, and many innovative business practices. To match the increasing pace of technological advancement across the globe, the United States must accelerate both the discovery of new scientific knowledge and the translation of that knowledge to useful purpose. Failure to act now could threaten the very principles – opportunity, social mobility, innovation – that have inspired our nation for the past century.

THE AMERICAN DREAM

> *"New frontiers of the mind are before us, and if they are pioneered with the same vision, boldness, and drive with which we have waged this war we can create a fuller and more fruitful employment and a fuller and more fruitful life."*
>
> – Letter from President Franklin D. Roosevelt to Vannevar Bush, November 17, 1944, prompting Vannevar Bush to write the historic report *Science, the Endless Frontier* [6]

The pathway to America's "endless frontier" is clear, but America is not on it.

For nearly two centuries, individuals throughout the world have been inspired by the American Dream. At its best, the Dream has implied opportunity for everyone, no matter his or her parents' socioeconomic status. It has been underpinned by America's freedom and democracy, and it has promised economic well-being to anyone willing to work hard. Education has been an important part of the Dream, embraced as the key to upward mobility even by those who had not been given the opportunity to receive an extensive education themselves. In

6. Franklin D. Roosevelt to Vannevar Bush, November 17, 1944, Washington, D.C., https://www.nsf.gov/od/lpa/nsf50/vbush1945.htm.

economic terms, the American Dream has meant having a decent job: not an easy or lucrative job, but one that could provide a livable wage and afford the next generation of Americans the opportunity for a better life than their parents had lived.

Some would, of course, view this scenario as overly idealistic; but millions of people born within this nation and around the world have *lived* the American Dream, including many members of the committee that prepared this report. Even with its imperfections, some of which are not insignificant, people from around the globe have equated the very essence of the United States with the American Dream, and as such this nation has represented a beacon of hope for much of the world.

Recent surveys conducted in countries around the world indicate that a substantial majority of respondents believe that the primary factor influencing their overall well-being is having an adequate job.[7] Early in this nation's history, such jobs were concentrated in agriculture; but with the advent of the industrial revolution, farming was displaced by manufacturing as the primary source of employment. Today, yet another economic revolution is occurring, driven by globalization and strongly rooted in technological advancement. The development of jet airliners has made it possible to move people and objects around the world nearly at the speed of sound; the development of modern information systems – telecommunications, processors, data storage – has made it feasible to move ideas, knowledge, and information around the world at the speed of light. In this new world, many no longer compete for a job with their neighbors across town; rather, they now compete with job candidates across oceans. These new global neighbors are highly motivated, increasingly well-educated, and often willing to work for a fraction of the wages and benefits to which American workers are accustomed. The consequences of this revolution in job creation have been and will continue to be profound, particularly for unskilled workers. Wages are increasingly being determined within a global labor pool, and many jobs at the lower end of the spectrum are disappearing altogether, often due to the effects of automation.

How is the American Dream faring in this new environment, in which economic competition is both increasingly globalized and increasingly technology-based?

People around the world still seek to come to America's shores in vast numbers, but disconcertingly, surveys reveal that in many countries, respondents no longer name America when asked where they would go to find a better life. For the first time in the nation's history,

7. See Jenny Chanfreau, Cheryl Lloyd, Christos Byron, Caireen Roberts, Rachel Craig, Danielle De Feo, and Sally McManus, *Predicting Wellbeing* (London: NatCen Social Research, 2013); Organisation for Economic Co-operation and Development Better Life Initiative, *Compendium of OECD Well-Being Indicators* (Paris: OECD Publishing, 2011); and Gallup-Healthways Well-Being Index, *State of American Well-Being* (Gallup, Inc. and Healthways, Inc., 2014).

young males in America are less well-educated than their fathers,[8] and they are likely to be less healthy as well.

Further, the overall opportunity gap is widening. The strongest indicator of whether a child will one day receive a college degree is whether or not that child's parents received degrees.[9] Youths in the lower quartile of academic performance whose parents are in the upper economic quartile are more likely to receive a college education than youths in the upper academic quartile whose parents reside in the lower economic quartile.[10] This imbalance poorly serves both the individual and the nation. As a consequence of these and other factors, a majority of Americans now believe that their children will experience an inferior quality of life to that which they themselves enjoyed.[11]

The predominant driver of GDP growth over the past half-century has been scientific and technological advancement.

Given the strong correlation of well-being with economic opportunity, the question arises: what must be done in economic terms to help preserve the American Dream? Since there is a strong correlation between job growth and gross domestic product (GDP), job creation on a large scale requires growing the nation's GDP. Numerous studies (one of which helped earn its author a Nobel Prize) have shown that the predominant driver of GDP growth over the past half-century has been scientific and technological advancement.[12] It is likely, given the current pace of progress in science and technology fields, that this will be equally true in the decades ahead, if not more so.

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8. National Center for Education Statistics, *Literacy in Everyday Life: Results from the 2003 National Assessment of Adult Literacy* (Washington, D.C.: Department of Education, 2007). Results showed that the functional literacy of U.S. males declined between 1992 and 2003.

9. Lumina Foundation, *A Stronger Nation through Higher Education* (Indianapolis, Ind.: Lumina Foundation, 2013).

10. Joshua S. Wyner et al., *Achievement Trap: How America is Failing Millions of High-Achieving Students from Lower-Income Families* (Lansdowne, Va.: Jack Kent Cooke Foundation, 2009).

11. Andrew Kahout, "What Will Become of America's Kids?" Pew Research Center, May 12, 2014, http://www.pewresearch.org/fact-tank/2014/05/12/what-will-become-of-americas-kids/.

12. Robert M. Solow, "Technical Change and the Aggregate Production Function," *The Review of Economics and Statistics* 39 (3) (August 1957): 312–320. See also George Evans, Seppo Honkapohja, and Paul Romer, "Growth Cycles," *American Economic Review* 88 (3) (1998); and World Economic Forum, *The Global Competitiveness Report 2001–2002* (New York; Oxford: Oxford University Press, 2002).

Virtually every new technological product is traceable to a research discovery, often one pursued with no application in mind.

But how is technological advancement created? Where does it originate? The fundamental feasibility of virtually every new technological product is traceable to a research discovery, often one pursued with no application in mind but for the sole purpose of expanding the frontiers of knowledge and understanding. For example, it seems doubtful that scientists exploring phenomena in solid-state physics or quantum mechanics in the mid-1900s executed their research for the express purpose of producing smartphones, laptop computers, global positioning systems (GPS), or imaging weather satellites. It seems equally unlikely that they foresaw the role their work would play in creating jobs for the factory workers, salespersons, accountants, and truck drivers associated with these products. And yet these were some of the many outcomes of their research. If we hope to continue to reap the benefits of research, then we must invest in research and improve the quality of STEM (science, technology, engineering, and mathematics) education at all levels and encourage more American youth to pursue careers in science, engineering, and technology (SE&T).

Innovators and entrepreneurs, many of whom are engineers, are an indispensable catalyst for transforming the results of research into capabilities and technologies that benefit society. But research is the foundation of their achievements and is what enables the creation of the jobs they provide for a broad spectrum of Americans. To expect continued technological advancement and job growth without investing in research is akin to attempting to operate an automobile factory without a loading dock for steel, aluminum, or rubber. In short, research is the lifeblood of a high-tech economy and plays a critical role in the economic and personal well-being of most citizens.

Research is generally categorized as either "basic" or "applied," with the former seeking to produce new knowledge without any specific application in mind, and the latter focusing on addressing a more specific problem or need. One might further divide basic research itself into two categories: one that is purely curiosity-driven, such as particle physics or astrophysics; and another that is fundamental but also relates to some category of opportunity, such as deciphering the human genome in search of cures for diseases.

Research is the lifeblood of a high-tech economy and plays a critical role in the economic and personal well-being of most citizens.

Each category serves an important function, but too often the impact of basic research (as opposed to applied research) has been undervalued. In this regard, Hunter Rawlings, President of the American Association of Universities, cites the iPhone, observing that

> it depends on seven or eight fundamental scientific and technological breakthroughs, such as GPS, multi-touch screens, LCD displays, lithium-ion batteries, and cellular networks. How many of those discoveries were made by Apple? None. They all came from research supported by the federal government and conducted in universities and government laboratories. Apple deserves credit for the final product, but it depends on government-sponsored research, much of it curiosity-driven rather than economically driven.[13]

America is permitting its highly successful system to atrophy.

Of course, the importance of industrial research and innovation should not be understated, but basic research, most of which is government-funded, is absolutely necessary to cultivate an ecosystem of research rich enough in new knowledge and ideas to enable breakthrough achievements.

The power of America's economic system and the role its universities, industry, and government have played in its growth have not gone unnoticed by other countries competing in the global job market. In fact, these growing powers seek not only to copy but to improve upon the American model. Instead of racing to meet the challenge, America is permitting its highly successful system to atrophy. This is not a formula for success in a highly competitive world.

But beyond the opportunity for economic success, there are other essential ingredients to the American Dream, including, most importantly, the opportunity to live in freedom and in a civil society governed by the rule of law (the province of research in the social sciences). The American Dream also preserves, and is itself sustained by, the opportunity to live a healthy life. In the past century, life expectancy in America grew from forty-nine years to seventy-nine years,[14] with biomedical research a significant contributor to the gain. And Americans now rightly expect that the food they eat, the water they drink, the air they breathe, and the environment they live in will be safe (the domains of agricultural, environmental, and earth sciences). While

13. "Hunter R. Rawlings III Alumni Day Remarks: The Lion in the Path," News at Princeton, Princeton University, February 25, 2014, http://www.princeton.edu/main/news/archive/S39/33/39I39/index.xml?section=topstories.

14. Elizabeth Arias, "United States Life Tables, 2003," *CDC National Vital Statistics Reports*, vol. 54, no. 14 (revised March 2007), 30–33; and Organisation for Economic Co-operation and Development, *OECD Better Life Index*, "Health – United States," http://www.oecdbetterlifeindex.org/topics/health/.

the American Dream rests on more than research alone, it is clear that the elements forming the foundation of the Dream – economic prosperity, improved quality of life through technology and medicine, opportunity for a quality education and a quality job, the hope of a better life for one's children – would begin to crumble without the vital reinforcement provided by the research enterprise.

THE HEALTH OF AMERICA'S RESEARCH ENTERPRISE

Given the critical role of research in sustaining the American Dream, it is useful to assess the health of the nation's research enterprise. This is not an easy task, particularly given the diversity of that enterprise. Historically, many years elapse between the time when the most basic research is performed and when its impact manifests in the form of newly created products and jobs. Further, research is itself a leading endeavor in the globalization of society such that the attribution of specific scientific accomplishments to a particular country or region is not always straightforward.

This latter circumstance has led some to question why America should not simply adopt a policy of letting other nations pay for the conduct of research and using their results to produce domestic products and jobs. Some nations have successfully employed this strategy in the past, particularly given complacent competitors such as the U.S. automobile industry of the latter part of the twentieth century. However, it will be increasingly difficult to follow such a scheme in the future: the pace of technological innovation is accelerating to the point where being second to market is now considered by many executives to be tantamount to failure. Craig Barrett, the retired CEO of Intel, has noted that 90 percent of the revenues Intel receives at the end of its fiscal year are derived from products that did not even exist at the beginning of that year.[15] Such a system would not work without a rich base of knowledge and discoveries.

There is a deficit between what America is investing and what it should be investing to remain competitive, not only in research but in innovation and job creation.

15. "Craig Barrett: Goodbye to Intel," BBC News, updated May 25, 2009, http://news.bbc.co.uk/2/hi/business/8058296.stm.

If research is a driver of GDP growth, as the evidence strongly indicates, then one metric of the adequacy of a nation's investment in research is the number of dollars invested in research as a percentage of GDP, relative to competitor nations.[16] By this measure of research intensity, the United States has fallen to tenth place among OECD nations.[17] Several major nations have been increasing their investment in research as a percentage of GDP at a rate considerably surpassing that of the United States. Further, U.S. investment in basic research as a percentage of GDP has actually declined over the past decade. Even government funding of biomedical research, generally strongly supported by the public because of its impact on health, has declined by 13 percent in real terms since 2003, when the effort to strengthen that endeavor began to wane.[18] These disturbing trends have created a deficit between what America is investing and what it should be investing to remain competitive, not only in research but in innovation and job creation. This "innovation deficit"[19] must be closed if we are to improve our global competitiveness and strengthen our economy.

How does one determine how much research is enough? There are, of course, many possible measures of research, both input and output. Perhaps the most fundamental of these is simply the number of capable researchers whose work is adequately funded. From a purely statistical standpoint, this measure would seem to favor nations with larger populations. But there is far more to the issue than sheer numbers of researchers: one thousand good researchers are unlikely to produce the work of one Albert Einstein. Quality and selectivity matter, and America's tradition of awarding funding based on expert peer-review evaluation of competitive research proposals has been key to the nation's past leadership in many fields of research.

Four significant sources of research funding exist in America: government (both federal and state), industry, universities, and philanthropy. In recent decades, as government reduced its share of the nation's investment in R&D from two-thirds to one-third, industry increased its share from about one-third to about two-thirds. But industry, given its need to react to the pressures of impatient financial markets, has concentrated its focus on *D* at the expense of *R*, with the demise of the iconic Bell Labs being a disconcerting example. This could be equated with eating one's seed corn without planting any for next year's harvest.

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16. This research investment could alternatively be stated as the number of dollars of GDP that each dollar invested in research must support.

17. OECD, *Main Science and Technology Indicators*, Table 2, "Gross Domestic Expenditures on R&D (GERD) as a Percentage of GDP."

18. American Association for the Advancement of Science, R&D Budget and Policy Program, "Trends in Research by Agency, 1976 – 2015," *Historical Trends in Federal R&D*, http://www.aaas.org/page/historical-trends-federal-rd (accessed August 15, 2014).

19. See http://www.innovationdeficit.org/.

It is important when making allocation decisions to distinguish between spending for present consumption and spending for investment.

Similarly, as state support for the nation's great public research universities has declined precipitously during the past decade, these institutions now find themselves in no position to substantially increase their research pursuits. In the United States, philanthropy is an important source of funding in specific areas of science, and although it continues to grow, philanthropy still makes up a small portion of the national research investment.[20]

This leaves the federal government as the essential funder for research that is conducted on a globally competitive scale but may not be driven by strong market incentives. It would seem to be a natural responsibility of government to support endeavors that clearly serve the public good, but which private entities are unable or unwilling to adequately support. Although America today faces a serious challenge in the form of its large national debt, it is important when making allocation decisions to distinguish between spending for present consumption and spending for investment, the latter being essential to the nation's future prosperity.

Research clearly represents an investment in the future. The need for a major federal role in funding research becomes all the more compelling given the evolution that has occurred across virtually all fields of research. To a substantial degree, the conduct of research has morphed from one scientist working in a laboratory to large teams of researchers working in a wide variety of fields, using sophisticated and expensive instrumentation, equipment, and informatics.

The most successful and widely emulated model for sustaining America's research enterprise has been and continues to be one wherein the primary funder of research, particularly basic (curiosity-driven or discovery-based) research, is the federal government, and the principal performers are the nation's universities, research institutes, and federal research laboratories. The translation of the results of this effort into jobs for the nation's citizenry will continue to be the responsibility of innovators, entrepreneurs, and the industrial sector. But if this translation is to be realized, the presently fractured links among government, industry, and academia in the United States must be greatly strengthened. Existing barriers to cooperation must be removed and the movement of individuals among these three sectors must be facilitated, since the most effective form of technology transfer is often the transfer of people.

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20. Fiona Murray, "Evaluating the Role of Science Philanthropy in American Research Universities," National Bureau of Economic Research Working Paper No. 18146 (June 2012), 23.

PRESCRIPTIONS FOR THE FUTURE HEALTH OF THE SCIENCE AND ENGINEERING RESEARCH ENTERPRISE

Given the above considerations, the American Academy of Arts & Sciences formed a committee composed of individuals with backgrounds in academia, industry, and government to offer recommendations that would strengthen the nation's competitiveness in the global job market through a revitalized research enterprise. The result was the formulation of three overarching prescriptions combined with a series of implementing actions. These recommendations are summarized below; additional background and observations related to each recommendation can be found in chapter three of this report.

These recommendations, if acted upon, will move the nation from gliding to propelling research, from an unguided to a strategic enterprise, and from a short-term to a long-term focus by establishing a more robust twenty-first-century research partnership across all sectors and by securing American competitiveness through sustainable federal funding for basic research. It is our hope that Americans from all backgrounds and professions will work together to achieve these goals and ensure that our nation continues to thrive for decades to come – and in doing so, they may sustain the American Dream for future generations.

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 2, page 21). 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,[21] 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 *multiyear 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.

From 1975 to 1992, the federal investment in basic research grew at an average annual inflation-adjusted rate of 4.4 percent (see Figure 2, page 21), despite serious political and economic challenges, including the 1973 oil embargo, the Great Inflation of 1979–1982, and the final tumultuous years of the Cold War. During this period, Republicans and Democrats, in spite of a number of policy differences, were in agreement that federal funding of basic research was a priority for the nation.

21. *America COMPETES Act*, Public Law 110-69, H.R. 2272, 110th Congress (January 4, 2007), https://www.govtrack.us/congress/bills/110/hr2272/text; and *American COMPETES Reauthorization Act of 2010*, Public Law 111-358, H.R. 5116, 111th Congress (January 4, 2011), https://www.govtrack.us/congress/bills/111/hr5116/text.

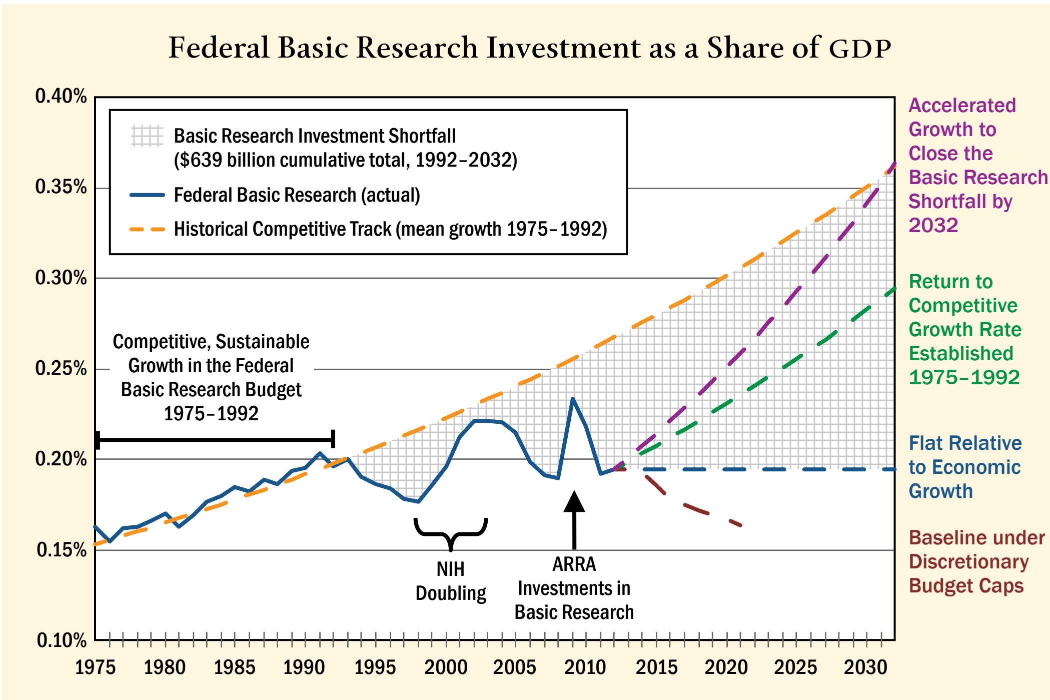

Figure 2

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.

Note: Orange trend line is a best fit (least squares regression) of federal obligations for basic research (percentage of GDP) between 1975 and 1992.

Refer to Appendix C to view this graph in constant dollars.

Source: 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, doi: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),[22] 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 (OSTP) 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 Research Council (NRC) report *Research Universities and the Future of America*.[23]
>
> ACTION 2.2c – We recommend that universities and the National Institutes of Health (NIH) gradually adopt practices to foster an appropriately sized and sustainable biomedi-

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22. 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."

23. 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).

cal research workforce.[24] 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 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 (AAAS), and the American Academy of Arts & 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 policy-makers in all sectors;

24. 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.

- 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 (see sidebar, page 97).

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[25] 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 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.

25. 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).

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,[26] 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.

26. 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*.

Chapter 1

Preserving the American Dream: Creating Quality Jobs and Securing our Quality of Life

"We lived the American dream, but the American dream may not survive."

– Norman R. Augustine, November 5, 2013, TEDxUSU[27]

2032 – WILL THE AMERICAN DREAM EXIST FOR CHILDREN BORN TODAY?

"Science and technology contribute immeasurably to the lives of all Americans. Our high standard of living is largely the product of the technology that surrounds us in the home or factory. Our good health is due in large part to our ever-increasing scientific understanding. Our national security is assured by the application of technology. And our environment is protected by the use of science and technology. ***Indeed, our vision of the future is often largely defined by the bounty that we anticipate science and technology will bring."***

– President Jimmy Carter, January 16, 1981,
The State of the Union Annual Message to Congress[28]

Having access to a good job is an important component of the American Dream, as is the opportunity to live a healthy and happy life. The products and industries that grow from advances in science, engineering, technology, and medicine not only stimulate the economy but raise the American standard of living, granting a more comfortable, healthier, and longer life to the general public. Without investments in research today, the breakthroughs that lead to tomorrow's new and better technologies and medical advances will not materialize. Yet as a nation, the United States has dropped to tenth place in R&D intensity, or national R&D investment as a percentage of GDP.[29] If we stay on our current path, China is forecast

27. Norman R. Augustine, "The Survival of the American Dream," TEDxUSU, Utah State University, November 5, 2013.

28. Jimmy Carter, "The State of the Union Annual Message to Congress," Washington, D.C., January 16, 1981, *The American Presidency Project*, http://www.presidency.ucsb.edu/ws/?pid=44541.

29. OECD, *Main Science and Technology Indicators*, Table 2, "Gross Domestic Expenditures on R&D (GERD) as a percentage of GDP."

to surpass the United States by this measure by 2022,[30] and is expected to surpass the United States as the world's dominant economic power by 2030 (see sidebar, page 36).[31] China already publishes more engineering articles annually than the United States[32] and, if recent trends persist, will outstrip the United States in the number of science and engineering articles published sometime around 2032.[33] As for basic (curiosity-driven or discovery-based) research, the U.S. federal investment as a share of GDP has fallen, returning to levels similar to those seen in 2000.[34] There is a growing deficit between what America *is* investing and what it *should be* investing to remain competitive, both in research and in innovation. This innovation deficit will constrain not only future industries and economic growth, but also job growth and the scientific advancements that improve quality of life, all of which are at the heart of realizing the American Dream.

Securing sustained federal investments in research is a critical component of closing this deficit, but the federal government alone cannot carry the nation's research enterprise. Combined action from federal and state governments, universities, and industry, each carrying out its role independently but in active cooperation with the others, is needed to work toward a national vision for SE&T in America. Federal government facilitates the generation of new knowledge by supporting the majority of basic research. Public and private universities perform most of the basic research (55 percent of the total national investment)[35] and public universities produce 64 percent of the workforce holding bachelor's degrees.[36] By and large, industry translates knowledge and scientific breakthroughs into use, creates new products and jobs, generates wealth, and fuels the economy. Industry is also a critical engine of innovation, performing

30. Battelle and *R&D Magazine*, *2014 Global R&D Funding Forecast*.

31. Kathryn J. Byun and Christopher Frey, "The U.S. Economy in 2020: Recovery in Uncertain Times," *Monthly Labor Review* 135 (1) (2012): 21–42.

32. National Science Board, *Science and Engineering Indicators 2014* (Arlington, Va.: National Science Foundation, 2014).

33. Assuming linear trends applied to the number of science and engineering articles published between 1997 and 2011. See ibid.

34. Ibid.

35. Ibid.

36. Chronicle of Higher Education, "Almanac of Higher Education 2012," http://chronicle.com/article/Degrees-Awarded-by-Type-of/133479/.

the majority of applied research and development in the United States.[37] Philanthropy plays an important role in supporting focused areas of research. By advancing education, research, jobs, innovation, and a greater understanding of the world around us, each entity has a part to play in creating and sustaining the American Dream. The national research enterprise must create partnerships that leverage the use of scarce talent and financial resources if the United States is to keep pace with the new economic powers of the rapidly changing global economic structure of the twenty-first century.

To a large extent, the future viability of the American Dream is tethered to the future health of American SE&T and, in particular, the science and engineering research enterprise. As striking as the above projections may be, the consequences of allowing the American Dream to fade reach far beyond global rankings. Our national identity, our culture of individualism, and the opportunities of an entire generation of motivated Americans are at risk if we fail to cultivate a fertile ecosystem for invention, ingenuity, and education. The American Dream can survive, but only if we are willing to make the bold, forward-looking changes necessary to recapture global leadership and restore competitiveness. Eighteen years from now, in 2032, when a child born today graduates from high school, will the American Dream still have meaning, or will it be forgotten?

37. It should be noted that certain industries, including those in the biomedical sector, have decreased their R&D investment in recent years. For example, between 2007 and 2012, nominal biomedical R&D expenditures within the private sector declined by $12.9 billion. See Justin Chakma, Gordon H. Sun, Jeffrey D. Steinberg, Stephen M. Sammut, and Reshman Jagsi, "Asia's Ascent – Global Trends in Biomedical R&D Expenditures," *The New England Journal of Medicine* 370 (1) (2014): 3 – 6.

RESEARCH AND INVENTION ARE FUNDAMENTAL TO THE AMERICAN DREAM

"America's growing economy is also a changing economy. As technology transforms the way almost every job is done, America becomes more productive and workers need new skills. Much of our job growth will be found in high-skilled fields like health care and biotechnology. So we must respond by helping more Americans gain the skills to find good jobs in our new economy."

– President George W. Bush, January 20, 2004,
Address Before a Joint Session of Congress on the State of the Union[38]

"In a global economy, the key to our prosperity will never be to compete by paying our workers less or building cheaper, lower-quality products. That's not our advantage. The key to our success – as it has always been – will be to compete by developing new products, by generating new industries, by maintaining our role as the world's engine of scientific discovery and technological innovation. It's absolutely essential to our future."

– President Barack Obama, November 17, 2010, Remarks by the President in Presenting
National Medals of Science and National Medals of Technology and Innovation[39]

The American Dream has held great meaning throughout the history of this nation, inspiring not only Americans but also people around the world. It has been a driving force behind many revolutionary achievements in human history. The American Dream lies at the heart of what it means to be American, even though it was never a uniquely American ideal. The American Dream consists of the powerful premise that hard work, opportunity, and playing by the rules bring prosperity, regardless of class, race, religion, or ethnicity. It is an assurance of *opportunity*, promising health, longevity, security, and freedom. Generation after

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38. George W. Bush, "Address Before a Joint Session of Congress on the State of the Union," Washington, D.C., January 20, 2004, *The American Presidency Project*, http://www.presidency.ucsb.edu/ws/index.php?pid=29646.

39. Barack Obama, "Remarks by the President in Presenting National Medals of Science and National Medals of Technology and Innovation," The White House, Washington, D.C., November 17, 2010, http://www.whitehouse.gov/the-press-office/2010/11/17/remarks-president-presenting-national-medals-science-and-national-medals.

generation of bold, hard-working, entrepreneurial individuals has followed this ethos, which has made America a powerhouse of innovation and economic prosperity. But this central ideal is now in jeopardy, and with it, the core of our national identity.

The viability of the American Dream is only as good as the strength of its roots: the opportunity for a good education, a good job, a good standard of living, and the chance for children to achieve more and have a better life than their parents did. Immediately following World War II, advancements in science opened the door for many hard working Americans to achieve greatness, despite humble beginnings. At the time, the United States found itself in possession of a glut of intellectual capital, as many of the world's leading scientists and engineers had relocated to the country during the war. The United States also dominated the global market for most manufactured goods, leading to a booming middle class. The federal government created new agencies dedicated to the advancement of science and technology – including the NSF, NIH, Office of Naval Research (ONR), and Atomic Energy Commission (AEC) (which later gave way to the Nuclear Regulatory Commission and the Department of Energy) – ushering in a new era of federally funded research and marking a nationwide recognition that the creation of new knowledge, products, and processes through scientific research held the key to many national pursuits, including economic growth, full employment, national defense, and better health.

Pathbreaking advances in health care, medicine, science, engineering, and technology followed. Jonas Salk's polio vaccine alone saved tens of thousands of lives in the seven-year period between 1952 and 1959.[40] The first bone marrow transplant to treat cancer was performed in 1957.[41] An astounding array of medicines to prevent, cure, or ease the discomfort of illness came pouring forth. Epidemiological research led to efforts to reduce smoking that have extended the lives of millions of Americans by decades. The space race put the first satellites into space and the first humans on the moon, and national defense efforts created the modern jet transport aircraft, as well as the beginnings of what would become the Internet and the devices we use to access it. As the world took its first steps toward a globalized future, new technologies and products were invented that made people's lives increasingly comfortable, including improved household appliances, automobiles, and plastics. New job opportunities in manufacturing and engineering were well within reach for anyone with a college, or even high school, education (8.1 percent and 43.7 percent of the American population, respectively,

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40. U.S. Department of Health, Education, and Welfare, "Poliomyelitis," *Health Information Series*, No. 8, Public Health Service Publication No. 74 (revised 1963).

41. E. Donnall Thomas, Harry L. Lochte Jr., Wan Ching Lu, and Joseph W. Ferrebee, "Intravenous Infusion of Bone Marrow in Patients Receiving Radiation and Chemotherapy," *The New England Journal of Medicine* 257 (1957): 491 – 496.

possessed a college degree or high school diploma in 1959).[42] The American Dream, albeit imperfect, was real for many of those willing to work hard to achieve a better life for themselves and their families.

> ***"Although basic research does not begin with a particular practical goal, when you look at the results over the years, it ends up being one of the most practical things government does.*** *For example, government-sponsored basic research produced the first laser. Today, less than three decades later, lasers are used in everything from microsurgery to the transmission of immense volumes of information, and may contribute to our Strategic Defense Initiative that promises to make ballistic missiles obsolete. Well, I think that over the past fifty years the government has helped build a number of particle accelerators so scientists could study high energy physics. Major industries, including television, communications, and computer industries, couldn't be where they are today without developments that began with this basic research."*
>
> – President Ronald Reagan, April 2, 1988,
> Radio Address to the Nation on the Federal Role in Scientific Research[43]

Hard work can still lead to prosperity. But the tectonic plates underlying this core ethos have shifted, putting the viability of the American Dream at risk. Over the past sixty years, SE&T have played an increasingly large and vital role in the economy, job growth, quality of life, and education of this country. Today, as discoveries and technological advancements are happening faster than ever, the pervasiveness of SE&T in our society and in the world is difficult to ignore. Sectors that require special skills, like engineering and high-tech manufacturing, have a long track record of providing some of the highest-paying jobs in the nation, and not only for scientists. In the manufacturing sector, average hourly compensation is 22 percent higher

42. U.S. Census Bureau, Historical Tables – Educational Attainment, Table A-2, "Percent of People 25 Years and Over Who Have Completed High School or College, by Race, Hispanic Origin and Sex : Selected Years 1940 to 2013."

43. Ronald Reagan, "Radio Address to the Nation on the Federal Role in Scientific Research," April 2, 1988, *The American Presidency Project*, http ://www.presidency.ucsb.edu/ws/ ?pid=35637.

than in the services sector.[44] Though some have argued that certain areas of SE&T – particularly those driving automation, such as robotics – may not generate many new employment opportunities and indeed may eliminate some opportunities; others hold that these same areas provide avenues for entrepreneurship and the creation of new industries and new occupations. Regardless of which turns out to be most accurate, change is coming fast. In this context, the nations best poised to make pioneering discoveries and rapidly translate those discoveries into new industries and new jobs will emerge as the world's leaders.

Following World War II, the United States was the largest market for any good or service in the world. That advantage is now receding. China has become the largest market for automobiles,[45] India is home to one of the largest textile industries in the world, and in both countries, the medical device industry is growing rapidly.[46] Other countries are also becoming competitors in critical areas such as automotives, electronics, and agriculture (see sidebar, page 36). These advances are important for international development, but if the United States is to retain its competitive edge in global markets, including in those industries that offer the high-paying, high-quality jobs for which Americans are vying, the United States must outperform its global competitors.

A quality education has long been the key to obtaining a good job. STEM education in particular is an increasingly central component to securing a future workforce prepared for and competitive in a highly technology-centric world. Yet on international standardized tests, U.S. fifteen-year-olds rank twenty-first in science and twenty-sixth in math among the thirty-four OECD nations.[47] The 2012 U.S. high school graduating class ranked thirty-first globally in math,[48] with serious weaknesses in translating real-world problems into mathematical models, pointing to a critical thinking deficit. Critical thinking is particularly important for STEM, which commands one of the highest-paying and fastest-growing job markets, with an average annual salary of $82,000 (total national average across all employment sectors is $45,700) and

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44. U.S. Department of Commerce and National Economic Council, "The Competitiveness and Innovative Capacity of the United States," January 2012, http://www.commerce.gov/sites/default/files/documents/2012/january/competes_010511_0.pdf.

45. "China Ends U.S.'s Reign as Largest Auto Market," Bloomberg News, January 11, 2010, http://www.bloomberg.com/apps/news?pid=newsarchive&sid=aE.x_r_l9NZE.

46. Bruce Einhorn, "Medical Device Makers Look East," *Bloomberg Businessweek*, November 14, 2013, http://www.businessweek.com/articles/2013-11-14/2014-outlook-medical-device-makers-look-east.

47. Organisation for Economic Co-operation and Development, "Programme for International Student Assessment (PISA) Results from PISA 2012: United States," http://www.oecd.org/unitedstates/PISA-2012-results-US.pdf.

48. Ibid.

a projected growth rate of 26 percent.[49] These jobs are competed for on a global scale; but if the United States continues on this path of disinvestment, American workforce competitiveness will be stunted.

A healthy economy is another vital part of generating opportunities for quality jobs. According to Okun's Law, America's GDP must rise by 3 percentage points in order to decrease its unemployment rate by 1 percentage point.[50] What can drive GDP growth at that rate? The past fifty years have demonstrated that innovation in SE&T is a critical component of a vibrant economy and a strong driver of industry, contributing to more than half of all annual economic growth in the United States.[51] Further, scientific research creates the foundational framework for fundamental breakthroughs that spawn new innovations and processes, from solar energy to the iPhone (see sidebar, page 37).

Standards of living have improved dramatically over the past sixty years in substantial part because of advances in science, engineering, and medicine that have generated new technologies, cured diseases, and created new knowledge at once-unimaginable speeds. A minuscule sampling of these achievements includes the creation of the polio vaccine, plastics, television, teleconferencing, cars, refrigeration, better plows, better harvesters, green energy sources, satellites, computers, the Internet, cell phones, smartphones, and the ability to treat, fight, and even defeat cancer.

These advances emerged from decades of scientific discovery, engineering creativity, and technological evolution, and they are progressing more rapidly today than ever before. After its advent in 1863, it took forty-six years for one-fourth of the U.S. population to have access to electricity. But only eighteen years after the invention of color television in 1951, a unit was installed in one out of every four households. The World Wide Web, meanwhile, was in use by 25 percent of the country's population within seven years of its debut for public use.[52] Smartphones, as we know them today, were adopted even faster: within seven years of their introduction, 56 percent of the U.S. population owned a smartphone.[53]

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49. Anthony P. Carnevale, Nicole Smith, and Jeff Strohl, *Recovery: Job Growth and Education Requirements Through* 2020 (Washington, D.C.: Georgetown Public Policy Institute Center on Education and the Workforce, 2013).

50. Ben Bernanke, "Recent Developments in the Labor Market," speech at the National Association of Business Economists, Arlington, Va., March 26, 2012.

51. Solow, "Technical Change and the Aggregate Production Function."

52. National Intelligence Council, *Global Trends 2030: Alternative Worlds* (Washington, D.C.: National Intelligence Council, 2012).

53. Aaron Smith, "Smart Phone Ownership 2013 Update," Pew Research Center, June 2013, http://www.pewinternet.org/2013/06/05/smartphone-ownership-2013/.

The final root of the American Dream, the opportunity to provide a better life for our children, has weakened. The current generation will be the first in U.S. history to be less well-educated than its parents,[54] and seven in ten young Americans find it difficult to save money, pay for college, or buy a home.[55] For many, the American Dream is fading.[56] The decisions made *today* by the nation's leaders in science and technology will carve a path that brings the nation either closer to or further from the American Dream.

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54. David Wessel and Stephanie Banchero, "Education Slowdown Threatens U.S.," *The Wall Street Journal*, April 26, 2012, http://online.wsj.com/news/articles/SB10001424052702304177104577307580650834716; and Claudia Goldin and Lawrence Katz, "The Race between Education and Technology: The Evolution of U.S. Educational Wage Differentials, 1890 to 2005," in *The Race between Education and Technology* (Cambridge, Mass.: Harvard University Press, 2008).

55. "Young, Underemployed, and Optimistic," Pew Research Center, http://www.pewsocialtrends.org/2012/02/09/young-underemployed-and-optimistic/.

56. David J. Lynch, "Americans Say Dream Fading as Income Gap Hurts Chances," Bloomberg News, December 11, 2013, http://www.bloomberg.com/news/2013-12-11/americans-say-dream-fading-as-income-gap-hurts-chances.html.

Slipping U.S. Competitiveness in Global Innovation

The United States has long been positioned at the front lines of innovation and as an early adopter of the new technologies that compose a large portion of the global product marketplace. Knowledge- and technology-intensive (KTI) industries contributed 40 percent of U.S. GDP and 27 percent of the world's GDP in 2012 and, as previously noted, an even larger fraction of the growth—and those numbers are only expected to increase.[1] But, at a time when global competitiveness could not be more important, the United States has lost its lead in innovation. As a nation, the United States has dropped to tenth place in its R&D investment as a percentage of GDP, and China is forecast to surpass the United States by this measure by 2022.[2] The United States still holds a large share of the high-tech manufacturing market—27 percent in 2012—but China is close behind: its share has skyrocketed from 8 percent in 2003 to 24 percent in 2012. A wave of smaller countries are also ramping up their engagement in the SE&T sphere, while the U.S. global share of R&D investment dropped from 37 percent in 2001 to 30 percent in 2012.[3]

Long-Term Outlook for R&D Expenditures in the United States, the European Union, and China

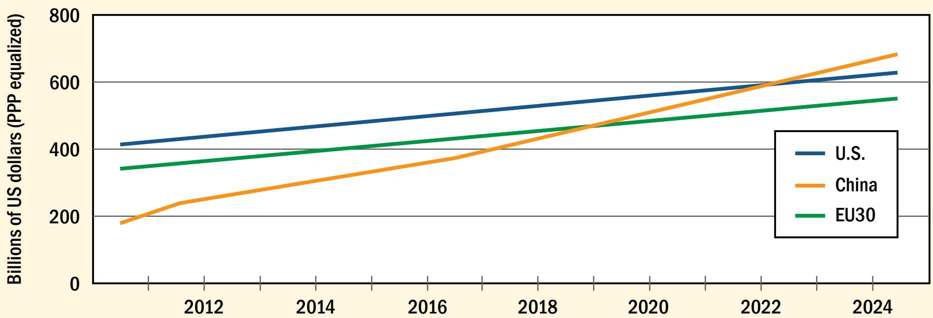

Figure 3

Long-Term Outlook for R&D Expenditures in the United States, the European Union, and China

PPP is purchasing power parity (used to normalize). Source: Reproduced from Battelle and *R&D Magazine, 2014 Global R&D Funding Forecast* (December 2013).

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1. National Science Board, *Science and Engineering Indicators 2014* (Arlington, Va.: National Science Foundation, 2014)
2. Battelle and *R&D Magazine, 2014 Global R&D Funding Forecast* (December 2013).
3. National Science Board, *Science and Engineering Indicators 2014*.

No Basic Research, No iPhone

Federally Funded Basic Research Made the iPhone Possible

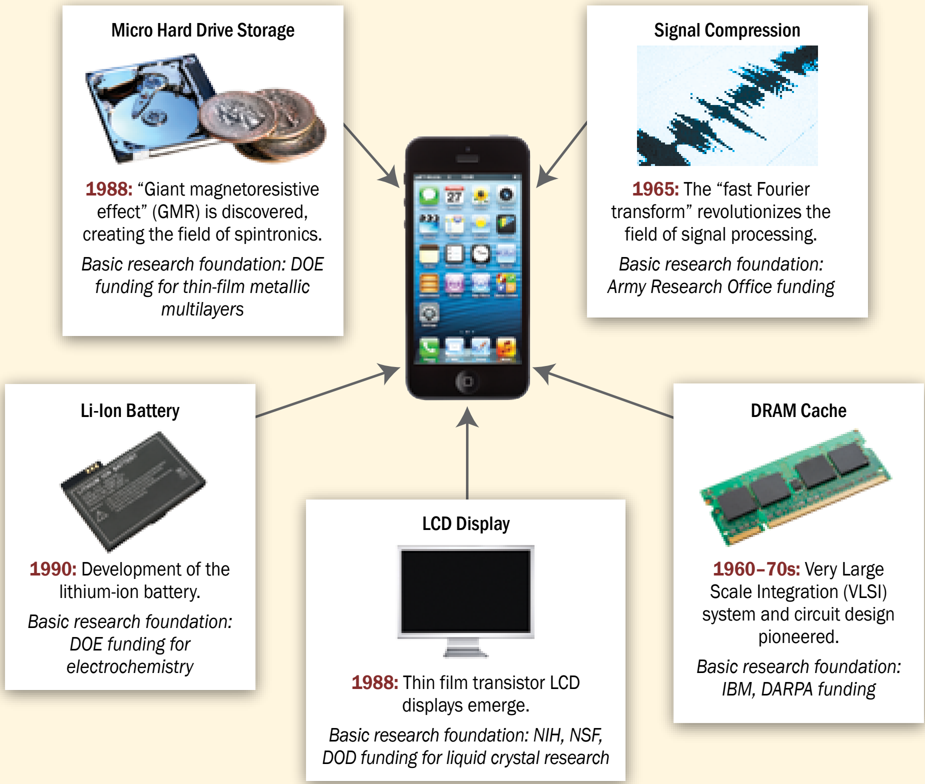

Figure 4

Federally Funded Basic Research Made the iPhone Possible

Source : The above image is a recreation of the diagram published in Office of Science and Technology Policy, *American Competitiveness Initiative : Leading the World in Innovation* (Washington, D.C. : Domestic Policy Council, 2006), 8.

Who invented the iPhone? To be certain, the design engineers and developers at Apple, Inc. are responsible for the construction and delivery of the device. But without decades of knowledge and technological advancements that in many cases grew out of federally funded basic research, the iPhone would not exist. A precursor to cellular communication, radiotelephony capabilities were advanced by the U.S. military. The underpinnings of the Internet were funded and developed by the (Defense) Advanced Research Projects Agency (DARPA) in the 1960s and 1970s. Around the same time, U.S. military and space programs did cutting-edge work on microchips, while also dramatically driving down the cost of these devices. The Global Positioning System also had military origins, while the multitouch screen was first developed in a University of Delaware laboratory supported by the NSF and the CIA.[1]

1. Yael Borofsky, Jesse Jenkins, and Devon Swezey, "Where Good Technologies Come From : Case Studies in American Innovation," Breakthrough Institute, December 10, 2010, http://thebreakthrough.org/archive/american_innovation.

CRISIS OR OPPORTUNITY: WILL AMERICA LEAD?

"If we do these things – invest in our people, our communities, our technology – and lead in the global economy, then we will begin to meet our historic responsibility to build a twenty-first-century prosperity for America."

– President Bill Clinton, January 20, 1999,
Address Before a Joint Session of Congress on the State of the Union[57]

"We cannot know where scientific research will lead. The consequences and spin-offs are unknown and unknowable until they happen. . . . But one thing is certain: If we don't explore, others will, and we'll fall behind. . . . It is an indispensable investment in America's future."

– President Ronald Reagan, April 2, 1988,
Radio Address to the Nation on the Federal Role in Scientific Research[58]

The American research enterprise is at a critical inflection point. The decisions that policymakers and leaders in science, engineering, and technology make over the next few years will determine the trajectory of American innovation for many years to come. We must not squander the opportunity to power the progress, impact, and creativity of American research; to stimulate job growth; and to fuel the nation's economy.

Over the past half-century, and especially in recent decades, the SE&T landscape has changed dramatically. The information revolution, the war on cancer, and the Human Genome Project are notable examples of SE&T efforts that have transformed society (see Focus Section A, page 43). Resulting trends include the boom in the total amount of information produced each year, the dramatic increase in the amount of computing power per dollar spent, and the plummeting cost of DNA sequencing (see Figure 5, page 39), which in turn have provided American researchers access to tools and data sets unimaginable just ten years ago. These developments have led to exciting new fields, such as bioinformatics, and continue to transform many existing fields, including data analytics and the behavioral sciences.

57. William J. Clinton, "Address Before a Joint Session of Congress on the State of the Union," Washington, D.C., January 20, 1999, *The American Presidency Project*, http://www.presidency.ucsb.edu/ws/?pid=57577.

58. Ronald Reagan, "Radio Address to the Nation on the Federal Role in Scientific Research," April 2, 1988, *The American Presidency Project*, http://www.presidency.ucsb.edu/ws/?pid=35637.

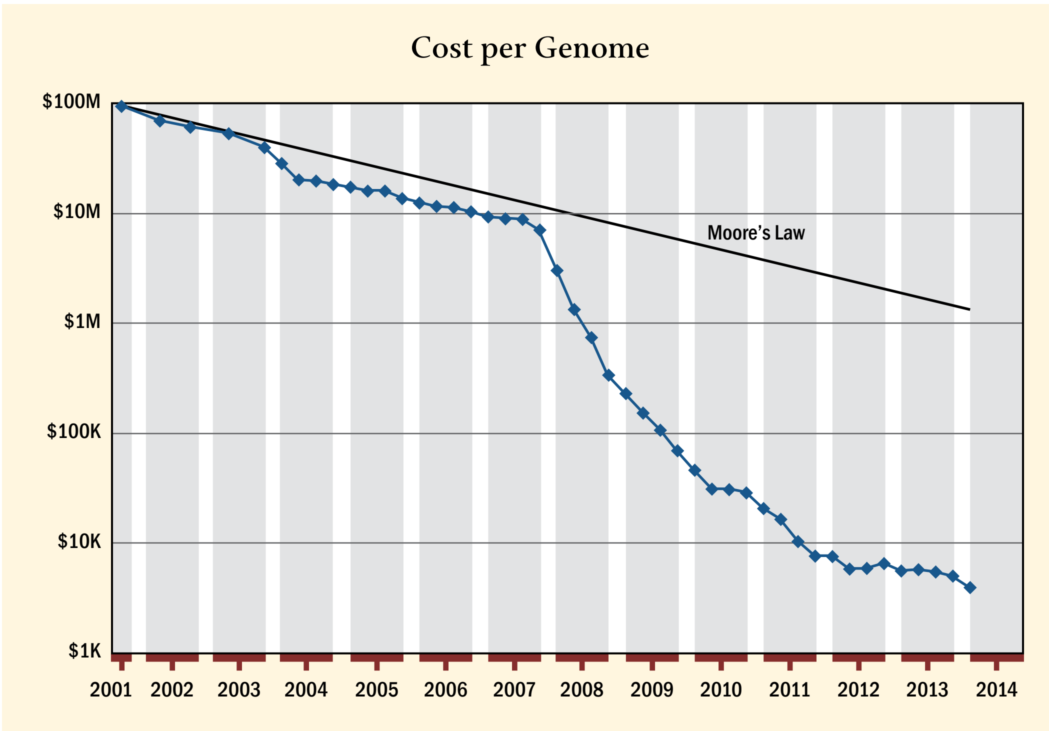

Figure 5

Rapid Reduction in the Cost of DNA Sequencing Ushered in a New Era of Biomedical Research

Moore's Law states that computer processing power will double every two years.

Source: National Human Genome Research Institute, "DNA Sequencing Costs – Data from the NHGRI Genome Sequencing Program (GSP)," https://www.genome.gov/sequencingcosts/.

America's research enterprise has been at similar inflection points before. Just after World War II, the country produced an extraordinary burst of invention and innovation in fields as diverse as electronics, mathematical algorithms, aviation, materials science, nuclear energy, and particle physics. The federal government provided the critical leadership needed at that juncture, shepherding the entire U.S. research system through a restructuring designed to leverage emerging technologies. Vannevar Bush, wartime science advisor to President Franklin D. Roosevelt and Director of the Office of Scientific Research and Development (OSRD), played a crucial role in building the framework upon which the NSF, NIH, and other key federal research agencies were built (for a deeper history, see Appendix B, page 120). He emphasized the importance of a review system in which research grants were evaluated by scientific peers. The establishment of the peer-review system enabled scientists and engineers in every discipline to support the most promising research projects fundamental to the advancement of science. While there are opportunities for fine-tuning the system, particularly in the face of recent shifts in the U.S. research landscape (see Focus Section A, page 43), this system of evaluation has been key to sustaining the world-class research that has placed the American research system at the forefront of the global endeavor.

On July 25, 1945, Vannevar Bush wrote to President Harry S. Truman to present his report *Science, The Endless Frontier*, which has since become something of an icon of American science policy. In his brief report, Bush addresses the importance of science to national security, health and medicine, and the public's well-being, emphasizing that "one of our hopes is that after the war there will be full employment," which will require "plenty of new, vigorous enterprises." Still, he emphasizes that "new products and processes are not born full-grown. They are founded on new principles and new conceptions which in turn result from basic scientific research. . . . Clearly, more and better scientific research is one essential to the achievement of our goal of full employment."[59]

Vannevar Bush viewed scientific research as "scientific capital," arguing that research funding should be considered not as a cost but as an investment in America's future, including its economy and the overall well-being of its citizens.[60] His vision led to a dramatic increase in the scientific capital that has driven the American innovation engine since World War II. The vast majority of American scientists and engineers who possess a graduate degree received federal research funding at some point in their career. Nearly 74 percent of academic postdoctoral research fellows received federal support in 2010 alone.[61] Critically, science Ph.D.s do not only stay in academia. Many focus their careers on developing new products and services, often becoming leaders – managers, directors, and executives – and job creators across a wide variety of sectors, including high-tech, pharmaceuticals, and advanced manufacturing.

While the policy foundation laid by Bush has served the United States well for almost seventy years, much has changed in the country and across the world. There are pressing problems that need attention, as well as unprecedented opportunities that demand new approaches. Growing pressures on the federal budget have led to cuts in many federal research agencies and programs. Researchers are spending more and more of their time writing and reviewing grant proposals, time that could otherwise be spent advancing science and building new businesses that apply the results of research in new and innovative ways.

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59. Vannevar Bush, *Science, The Endless Frontier* (Washington, D.C. : Government Printing Office, 1945), 2.

60. Ibid.

61. National Science Board, *Science and Engineering Indicators 2014*, 5-34, 5-35, and Appendix Table 5-21, "Academic SEH Doctorate Holders with Federal Support, by Degree Field, Research Activity, and Type of Position : 1973 – 2010."

> *"First, we must have plenty of men and women trained in science, for upon them depends both the creation of new knowledge and its application to practical purposes. Second, we must strengthen the centers of basic research which are principally the colleges, universities, and research institutes. These institutions provide the environment which is most conducive to the creation of new scientific knowledge and least under pressure for immediate, tangible results. With some notable exceptions, most research in industry and Government involves application of existing scientific knowledge to practical problems. It is only the colleges, universities, and a few research institutes that devote most of their research efforts to expanding the frontiers of knowledge."*
>
> – Vannevar Bush, July 1945, *Science, The Endless Frontier*[62]

One of the most exciting developments has been the changing nature of innovation. In Vannevar Bush's day, research and invention were viewed separately from prototype development and product design. Today, most innovative and successful companies do not think of innovation as a linear, step-by-step process that moves from research to invention, then prototype, then product design, then marketing. Instead, using collaborative tools and the Internet, ideas and data flow back and forth between the different groups involved in turning research into products and services (see Figure 6, page 42). In such an innovation ecosystem, technology is not "transferred" as if it could be wrapped in a box and moved from the research team to the product development team. Instead, there is an ongoing iterative dialogue between researchers, developers, marketing teams, and the customer support teams who deal with flaws that occasionally appear in the original design. Innovation occurs in a web in which ideas, data, and people move freely, improving both the quality and speed of work.

Other nations have launched initiatives that encourage the transfer of people across sectors, including Germany (Fraunhofer Institutes), Taiwan (ITRI, the Industrial Technology Research Institute), and Singapore (A*STAR, the Agency for Science, Technology and Research). The nation that fosters partnerships and cooperation across government, industry, and academia, as well as a balanced portfolio of basic and applied research, will lead the globe in scientific and technological progress.

62. Bush, *Science, The Endless Frontier*, 2.

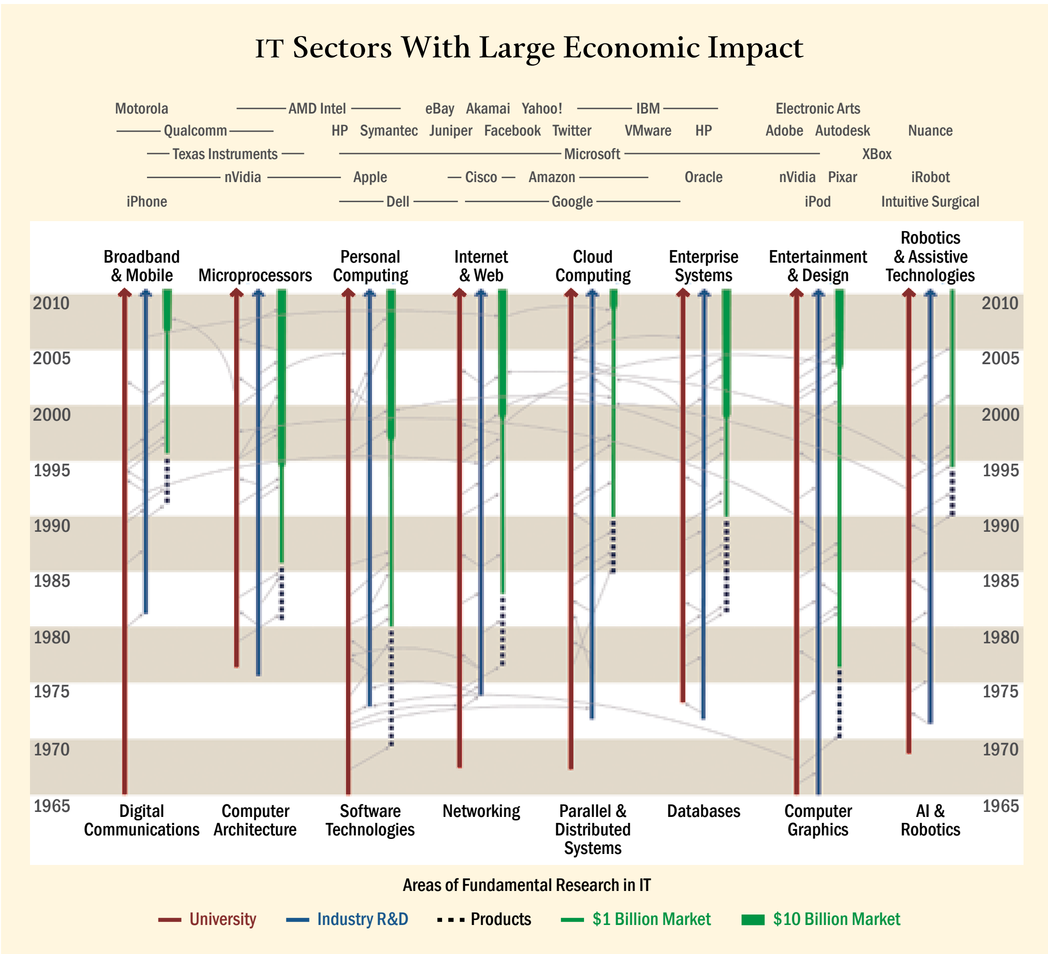

Figure 6

Innovation is Not Linear, but a Highly Interconnected Web

Examples of the contributions of federally supported fundamental research to the creation of information technology (IT) firms and products with large economic impact. Red tracks: university-based research. Blue tracks: industry R&D. Dashed black lines: periods following the introduction of significant commercial products resulting from fundamental research. Green lines: billion-dollar-plus industries (by annual revenue) stemming from fundamental research. Thick green lines: achievement of multibillion-dollar markets by some industries. Arrows between tracks: multidirectional flows of ideas, technologies, and people. Top rows: present-day IT market segments and representative U.S. firms and products whose creation was stimulated by the research represented by the red and blue vertical tracks. Bottom row: areas of fundamental research in IT.

Source: National Research Council, *Continuing Innovation in Information Technology* (Washington, D.C.: The National Academies Press, 2012), 3.

FOCUS SECTION A

Responding to Shifts in the Scientific Landscape

The scientific landscape has changed dramatically since the dawn of major federally funded academic research in the United States following the end of World War II. Key advancements in fields like biology, medicine, physics, information technology, and engineering have accelerated the development of groundbreaking technologies and processes, allowing the products of scientific research to permeate and greatly benefit society, all while increasing global connectivity. Notable milestones and some of their transformative impacts on the world are described here, along with new challenges facing federal and state governments, universities, and business and industry.

War on Cancer

The war on cancer was sparked by President Nixon's signing of the National Cancer Act of 1971.[63] Funding for the National Cancer Institute (NCI) grew rapidly, and by 1991 overall rates of cancer started to drop.[64] This period heralded groundbreaking discoveries not only in the *treatment* of cancer, but in our *understanding* of the origins of cancer and the mechanisms of cellular function as well.

Human Genome Project

The 1953 discovery of the DNA double-helix by Francis Crick and James Watson, combined with Frederick Sanger's DNA sequencing techniques in the 1970s, spurred a national interest in genetics, particularly in relation to genetic mutations. In 1990, the National Center for Human Genome Research (NCHGR), now the National Human Genome Research Institute (NHGRI), released a research plan to sequence at least 90 percent of the human genome.[65] This decade-long research effort[66] ushered in a new era of biology that leverages powerful genetic techniques like recombinant DNA technology to explore life and disease states from single cells to whole organisms. In addition, the Human Genome Project has had an estimated economic impact of nearly $1 trillion since 1988, including the generation of more than 4.3 million job-years of employment, amounting to a return of 178:1 on the federal government's $3.8 billion investment.[67] More important, it provides a key to better health for all people.

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63. *National Cancer Act of 1971*, Public Law 92-218, S. 1828, 92nd Congress (December 23, 1971).

64. National Cancer Institute, Office of Government and Congressional Relations, "The National Cancer Act of 1971," http://legislative.cancer.gov/history/phsa/1971.

65. National Human Genome Research Institute, "An Overview of the Human Genome Project," November 8, 2012, https://www.genome.gov/12011239.

66. International Human Genome Sequencing Consortium (Eric S. Lander et al.), "Initial Sequencing and Analysis of the Human Genome," *Nature* 409 (2001): 860–921.

67. Battelle Technology Partnership Practice for United for Medical Research (UMR), "The Impact of Genomics on the U.S. Economy," June 2013, http://web.ornl.gov/sci/techresources/Human_Genome/publicat/2013BattelleReportImpact-of-Genomics-on-the-US-Economy.pdf.

Information Revolution

Beginning with the transistor and graduating to the integrated circuit and beyond, the progression of ever more powerful computer chips has opened the floodgates for generation after generation of supercomputers, mobile devices (such as laptops, tablets, and smartphones), and enhanced network connectivity (including the Internet, the cloud, and broadband). New computing technologies permeate every corner of society – from watches and pacemakers to cars, aircrafts, and satellites – and have transformed day-to-day life around the globe.

Globalization

The fall of the Soviet Union allowed a large segment of the world to learn about and practice capitalism, expanding markets for goods and services and increasing competition to occupy those businesses. In particular, China has grown to become a global economic force and is on the fast track to becoming a major player in science and technology through intensified state investments in R&D and STEM education. In the face of fierce global competition, American companies are going offshore for workers and markets, including for the conduct of R&D. This has led to broad and multifaceted consequences in shaping American industries, the future workforce, and the role played by research universities.

Challenges to Universities

American research universities rightly boast of being the best in the world. But our universities, especially our public institutions, face enormous political and economic pressures that are likely to force tradeoffs between research and education, especially as federal research funding maintains a flat or downward trajectory. These pressures could be expected to weaken the traditional government-university (GU) partnership that has been key to the nation's leadership in science and technology. This comes at a time when strengthening cooperation across sectors – government (federal and state), universities (public and private), and industry – should be a national priority.

Challenges to Industry

American industries fuel economic growth and the nation's job market. But today they are challenged to create high-quality, high-paying jobs for Americans while maintaining leadership in highly competitive global markets, especially those in science, engineering, technology, manufacturing, and medicine. At the same time, U.S. industry faces pressure to seek short-term gains, which may come at the expense of long-term progress. Barriers to partnerships across industry, business, federal and state governments, and universities also slow the progress of the research enterprise as a whole.

Challenges to Government

Government at all levels is challenged to meet public needs and expectations in the face of severe financial constraints and uncertainties. States are reducing their investments in public universities. The federal government faces growing national debt and difficult policy decisions, and federal agencies must balance budget constraints with expectations to maintain both U.S. global leadership in science and engineering research and the well-being of the nation's citizenry.

FOCUS SECTION B

A "Gathering Storm" – U.S. Challenges in an Increasingly Competitive and Interconnected World are Met by Uncertainty and Lack of Resolve

The foreboding phrase "the gathering storm" appeared in the title of the 2007 National Academies NRC report *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*[68] and again in the 2011 update *Rising Above the Gathering Storm, Revisited: Rapidly Approaching Category 5*.[69] The National Academies' description of the initial report reads:

> In a world where advanced knowledge is widespread and low-cost labor is readily available, U.S. advantages in the marketplace and in science and technology have begun to erode. A comprehensive and coordinated federal effort is urgently needed to bolster U.S. competitiveness and pre-eminence in these areas. This congressionally requested report by a pre-eminent committee makes four recommendations along with 20 implementation actions that federal policy-makers should take to create high-quality jobs and focus new science and technology efforts on meeting the Nation's needs, especially in the area of clean, affordable energy.[70]

The *Gathering Storm* report was well received by President George W. Bush and Congress and led to the President's American Competitiveness Initiative (ACI) and the America COMPETES Act of 2007 (reauthorized in 2010)[71] – a remarkable response to a policy report. What seemed to get the attention of most politicians were America's poor rankings on a long list of key indicators relating to science and technology, education and training, and innovation and competitiveness among nations. But in spite of getting the attention of policy-makers, many of the recommendations have not been enacted. The NRC committee stated the situation in stark terms in its 2011 update:

> So where does America stand relative to its position of 5 years ago when the "Gathering Storm" report was prepared? The unanimous view of the committee members participating in the preparation of this report is that our Nation's outlook has not improved but rather has worsened.[72]

There are many reasons for the disappointing policy response, and one can point to hundreds of reports containing thoughtful recommendations authored by distinguished committees that have fared less well. The nation continues to face painful decisions in its effort to reduce

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68. Institute of Medicine et al., *Rising Above the Gathering Storm*.

69. Institute of Medicine, National Academy of Sciences, and National Academy of Engineering, *Rising Above the Gathering Storm, Revisited: Rapidly Approaching Category 5* (Washington, D.C.: The National Academies Press, 2010).

70. National Academies Press, catalog description of *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*, http://www.nap.edu/catalog.php?record_id=11463.

71. Institute of Medicine et al., *Rising Above the Gathering Storm, Revisited*.

72. Ibid., 5.

the national debt while continuing its economic recovery from the Great Recession. Some of those budgetary choices inevitably will not be popular with large segments of the American population, and progress is further thwarted by deep ideological differences across the country and in Washington. But America's standing in science and technology research and education and what that standing means for the future of the country in an increasingly competitive world should command the attention of the American public and its elected representatives, regardless of individual political persuasions and party affiliations.

Many other reports from well-known and respected organizations and councils, some of which are discussed in more detail below, have added to the *Gathering Storm* reports, generating a groundswell of support from leaders in industry, academia, and government for policies aimed at strengthening and stabilizing America's research enterprise.

Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future (2007) and *Rising Above the Gathering Storm, Revisited: Rapidly Approaching Category 5* (2011)

The *Gathering Storm* reports make clear that America's standing is eroding rapidly. Indeed, in 2007, the chairman of the "Gathering Storm" committee, former Lockheed Martin Chairman and CEO Norman R. Augustine, wrote a separate paper, also published by the National Academies, with the telling title "Is America Falling Off the Flat Earth?"[73] Recommendations from the *Gathering Storm* reports that have yet to receive action include:

- Doubling the real federal investment in basic research in the physical sciences, math, and engineering over seven years while at least maintaining the real spending levels in the biomedical sciences;
- Rebuilding the competitive research ecosystem by reforming the nation's tax, patent, immigration, and litigation policies; and
- Offering a one-year visa extension to Ph.D. recipients in STEM fields and providing a path to citizenship for those who complete their degrees in fields of national need.

73. National Research Council, *Is America Falling Off the Flat Earth?* (Washington, D.C.: The National Academies Press, 2007).

ARISE – Advancing Research In Science and Engineering: Investing in Early-Career Scientists and High-Risk, High-Reward Research (2008)[74]

ARISE, a 2008 report from the American Academy of Arts & Sciences, focuses on two issues central to advancing the nation's research efforts: 1) support for early-career faculty; and 2) encouragement of high-risk, high-reward, potentially transformative research. The committee, comprising leaders from business and academia, made recommendations to federal agencies, universities, and private foundations, including:

- *(to universities)* Developing or strengthening mentor programs to encourage early-career faculty, reconsidering promotion and tenure policies for early-career faculty, and accepting greater responsibility for faculty salaries;
- *(to private foundations)* Capping the number of start-up and first awards made to a single investigator to spread the wealth; and
- *(to federal agencies)* Establishing multiyear awards for early-career faculty, adopting career-stage-appropriate expectations for grant funding, fostering transformative research through targeted programs and grant mechanisms, and establishing metrics to evaluate the success of grant programs.

A New Biology for the 21st Century: Ensuring the United States Leads the Coming Biology Revolution (2009)[75]

The *New Biology* report from the NRC calls for greater integration of the biological sciences with other STEM disciplines – physics, chemistry, computer science, engineering, and mathematics – in order to take full advantage of the new and powerful tools that have arisen at the intersections of these disciplines and to tackle the challenges facing society in the areas of food, environment, energy, and health. The committee recommends establishing a national New Biology Initiative that:

- Has inter-agency leadership operating within a timeline of at least ten years;
- Engages scientists from across disciplines to find solutions to societal challenges; and
- Invests in education of New Biologists and provides opportunities for students seeking to use science to solve real-world problems.

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74. American Academy of Arts & Sciences, *ARISE – Advancing Research In Science and Engineering: Investing in Early-Career Scientists and High-Risk, High-Reward Research* (Cambridge, Mass.: American Academy of Arts & Sciences, 2008).

75. National Research Council, *A New Biology for the 21st Century* (Washington, D.C.: The National Academies Press, 2009).

Managing University Intellectual Property in the Public Interest (2010)[76]

In 2010, the NRC released its report evaluating the impact on university technology transfer of the Bayh-Dole Act of 1980, which awarded universities and other nonprofit organizations significant control over managing intellectual property (IP) arising from federally funded research conducted at these institutions. The committee concluded that the act introduced a system that was more effective than the previous system in transferring the products of federally funded university research to the public, and while no better alternative system has been formally proposed, improvements could be made to the current system, including:

- *(at universities)* Pursuing patenting and licensing practices that maximize the beneficial impact of technologies on society;
- *(at universities seeking to encourage entrepreneurship)* Instituting an expedited procedure for licensing university-generated technology to start-up enterprises formed by faculty, staff, or students of the institution; and
- *(at university technology transfer offices)* Exploring arrangements with private research sponsors to accelerate the process of negotiating licensing terms.

Research Universities and the Future of America: Ten Breakthrough Actions Vital to our Nation's Prosperity and Security (2012)[77]

This report, released by the NRC in 2012, offers ten recommendations to strengthen partnerships among the nation's research universities; federal and state governments; business and industry; and philanthropy, including:

- Doubling the level of basic research conducted by the NSF, NIST, and DOE Office of Science, as authorized by the America COMPETES Act;
- Increasing federal investment in graduate education to "a level sufficient to produce the new knowledge and educated citizens necessary to achieve national goals";
- Evolving a more "peer-to-peer" relationship between business and higher education, rather than one of a "customer-supplier" nature;
- Advancing technology transfer by improving university management of intellectual property; and

76. National Research Council, *Managing University Intellectual Property in the Public Interest* (Washington, D.C.: The National Academies Press, 2010).

77. National Research Council, *Research Universities and the Future of America*.

- “Increasing university cost-effectiveness and productivity in order to provide a greater return on investment for taxpayers, philanthropists, corporations, foundations, and other research sponsors.”

Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics (2012)[78]

In February 2012, the President’s Council of Advisors on Science and Technology released their report on STEM education, entitled *Engage to Excel*. The report calls for the federal government to catalyze the adoption of proven teaching practices and classroom approaches that more actively engage students, with the goal of improving the quality of education and strengthening retention in the fields of students who graduate with STEM degrees. Recommended actions include:

- Creating a Presidential Council on STEM Education with leadership from both the academic and business communities with the goal of transforming undergraduate STEM education;
- Developing new approaches through a multi-campus five-year initiative to remove the “mathematics bottleneck” that prevents many students from pursuing STEM majors;
- Training faculty in the best teaching practices through discipline-focused programs;
- Establishing public-private partnerships to support successful STEM programs; and
- Developing metrics to evaluate the effectiveness of STEM education.

Transformation and Opportunity: The Future of the U.S. Research Enterprise (2012)[79]

In November 2012, PCAST released another report, *Transformation and Opportunity*, that focused on strengthening the U.S. research enterprise. The report observed that a growing corporate emphasis on short-term returns has eroded private-sector support of basic and early-applied research, resulting in a research gap to be filled by the nation’s research universities. As basic and early-applied research form the foundation for new industries, PCAST recommended a number of actions to strengthen university research and national R&D, including:

78. President’s Council of Advisors on Science and Technology, *Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics* (Washington, D.C.: Executive Office of the President of the United States, 2012).

79. President’s Council of Advisors on Science and Technology, *Transformation and Opportunity*.

- Increasing total national R&D expenditures from government, industry, and universities to 3 percent of GDP;
- Increasing the stability and predictability of federal funding for research and research infrastructure and facilities, possibly through a closer coupling of multiyear authorizations to actual R&D appropriations or a cross-agency multiyear program and financial plan similar to DOD's Future Years Defense Program;
- Making the R&E Tax Credit permanent and increasing its usefulness to small and medium-sized R&D-intensive enterprises by instituting refundable tax credits, transferable tax credits, and/or modifications in the definition of "net operating loss"; and
- Eliminating regulations and policies within the OMB and other offices that do not add value or enhance accountability, especially those that decrease the productivity of the nation's research universities.

ARISE 2: Unleashing America's Research and Innovation Enterprise (2013)[80]

The American Academy of Arts & Sciences released its second report on Advancing Research In Science and Engineering, *ARISE* 2, in May 2013. The report calls for greater cooperation across government, academia, and the private sector; and a nationwide transition from interdisciplinary to transdisciplinary research, which requires a deeper integration of the physical sciences and engineering (PSE) and the life sciences and medicine (LSM) with the aim of finding solutions to complex challenges, particularly grand challenges. Recommendations for achieving these goals include:

- Expanding education paradigms and training programs to model transdisciplinary approaches;
- Establishing "grand challenges" that motivate the integration of efforts and approaches across academia, industry, and government; and
- Enhancing permeability between industry and academia at all career stages.

80. American Academy of Arts & Sciences, *ARISE 2: Unleashing America's Research and Innovation Enterprise* (Cambridge, Mass.: American Academy of Arts & Sciences, 2013).

Convergence: Facilitating Transdisciplinary Integration of Life Sciences, Physical Sciences, Engineering, and Beyond (2014)[81]

The NRC's 2014 *Convergence* report explores and summarizes existing mechanisms to foster convergence across scientific disciplines with the goal of achieving transdisciplinarity, and offers strategies to overcome implementation challenges, including:

- Fostering informal gatherings of faculty with shared interests in convergence problems and topics, which may also contribute to advancing convergent candidates for faculty positions;
- Establishing mechanisms for faculty to hold joint appointments across departments and schools and initiating executive-in-residence programs to bring insights from practitioners in industry; and
- Implementing flexible course requirements for graduate students that enable them to fill gaps in knowledge needed to undertake convergent projects and/or the ability for graduate students to name and shape the area of their degree.

81. National Research Council, *Convergence: Facilitating Transdisciplinary Integration of Life Sciences, Physical Sciences, Engineering, and Beyond* (Washington, D.C.: The National Academies Press, 2014).

Chapter 2

Unlocking Tomorrow's Inventions by Driving Better Policies Today

THE GOVERNMENT-UNIVERSITY-INDUSTRY PARTNERSHIP: AN IMPORTANT FOUNDATION READY TO BE MODERNIZED

One of the most transformative outcomes of Vannevar Bush's 1945 report was the establishment of a strong research partnership between the nation's universities and the federal government; or more precisely, the research funding agencies of the federal government. That arrangement has worked well, even in difficult times, and there is no evidence to suggest that it is not the optimal strategy for the future. If anything, we must find new ways to strengthen the government-university research partnership by increasing the participation of business and industry and addressing existing policy issues that pose barriers to stronger cooperation. The nation needs to forge a true government-university-*industry* (GUI) research partnership, including state governments as well as philanthropy. However, the GU partnership is in trouble and the university-industry (UI) and government-industry (GI) partnerships have seldom been strong in the past. All three sectors have been slow to make changes that would involve business and industry as more engaged partners.

The Universities

American universities remain the envy of much of the rest of the world, in part because their faculty and students perform more than half (55 percent) of the nation's basic research,[82] including that which leads to transformative breakthrough discoveries. By providing their students with unparalleled hands-on experience in the laboratories, universities are also instrumental in creating the science and engineering workforce the country needs if it is to remain competitive in the global marketplace.

One reason the United States has so many highly ranked universities is that they compete intensely with one another – within states and across the country – for promising students and star faculty, who in turn compete for federal research grants that are awarded based on expert peer review. Competition is the American way and has generally been accepted as the best way to assure quality and performance. Peer review is a demanding process that works only if the national research community supports it and is willing to participate by submitting proposals and serving as unpaid reviewers. While no better process has been found, when success rates among those seeking grants are low, as they have been in recent years, the system becomes wasteful of the time and talent of those writing and reviewing proposals, as well as the program officers at federal agencies who make the final decisions. It also discourages young people from pursuing careers in science and engineering. There are legitimate criticisms of peer review: it can favor conservative ideas over bold ones, discouraging researchers from

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82. National Science Board, *Science and Engineering Indicators 2014*.

proposing high-risk but potentially high-reward projects; it can favor senior researchers with established track records at the expense of early-career investigators; and it is not effective in addressing the underrepresentation of women and ethnic minorities in many fields of science and engineering. In its 2008 report *ARISE – Advancing Research In Science and Engineering* (see Focus Section B, page 46)[83] the American Academy of Arts & Sciences addresses the challenge for early-career researchers and for investigators seeking funding for high-risk, potentially transformative research. The funding agencies are acutely aware of these concerns and have piloted a number of approaches over the years to address them, including NIH's portfolio of Transformative Research Awards (T-R01s), New Innovator Awards, and Pioneer Awards, and the agency-funded Presidential Early Career Award for Scientists and Engineers (PECASE).[84] However, all agencies do not implement peer review in the same way, and the specific review criteria vary depending on the mission of the agency and the nature of the proposed research.

The American system of higher education is also very diverse in terms of institutional size, location, disciplinary focus, degree offerings, and academic requirements. This diversity of the American research system is a great strength, providing large segments of the nation's population with educational opportunities that otherwise would not exist. There are currently 4,495 post-secondary degree-granting institutions spread across the nation.[85] Of these institutions, those that engage in research are home to outstanding faculty who are not only internationally recognized researchers, but practicing educators as well.

One indicator of the global standing of American universities is the continuing stream of bright young men and women who come from all corners of the earth to study here and, in many cases, remain to establish careers, start companies, create jobs, and contribute to the U.S. economy. In 2010, 42 percent of Ph.D. graduates in science and engineering were foreign born, as were more than one-third of master's graduates.[86] But once foreign-born students graduate, existing immigration policies make it difficult or impossible for even the best-educated individuals to become permanent residents or citizens.

A second positive indicator is the key role that U.S. researchers play in international collaborations. In the biomedical sciences, the International Human Genome Project, led on the U.S. side by the NIH with substantial funding from the DOE, involved major collaborations with

83. American Academy of Arts & Sciences, *ARISE – Advancing Research In Science and Engineering*.

84. Federal agencies participating in the PECASE program include the USDA, Department of Commerce (DOC), DOD, DOE, Department of Education (DOEd), NIH, Department of Veterans Affairs (VA), Environmental Protection Agency (EPA), NASA, NSF, and the Smithsonian Institution.

85. U.S. Department of Education, Institute of Education Sciences, National Center for Education Statistics, *Digest of Education Statistics, 2011, NCES* 2012-001, Table 5.

86. National Science Board, *Science and Engineering Indicators 2014*.

scientists in the United Kingdom, France, Australia, and Japan.[87] Most of the actual genome sequencing was performed in university laboratories and research centers. At the Large Hadron Collider (LHC) at the CERN (European Organization for Nuclear Research) laboratory in Switzerland and France, particle physicists from U.S. research universities were among the scientific leaders who first observed a particle consistent with the Higgs boson.[88] The DOE and NSF also contributed substantial funding for the construction of the LHC accelerator and its detectors.[89] Because of the large cost of particle accelerators, this kind of international collaboration will be increasingly necessary in the future, whether the next machine is built in the United States or elsewhere. To participate in and benefit from the excellent science being performed the world over, it is imperative that we become a stronger partner in international science collaboration.

In astronomy and astrophysics, international cooperation has long been essential to building the most advanced telescopes, which must be sited where the viewing is best: atop Mauna Kea in Hawaii and Cerro Pachon in Chile, or in Earth's orbit, as is the case with the Hubble Space Telescope (HST). The HST is a joint project between NASA and the European Space Agency (ESA) that provides observing opportunities to the international astronomy community based on a competitive proposal process.[90] It is standard practice with federally funded telescopes to encourage cost sharing and to make observing time available to the international community.

International scientific collaboration has always been important to the advancement of science, particularly through basic research. Major advances often come from assembling the minds and skills of experts, and the U.S. national interest is best served by ensuring that American researchers are adequately supported and working at the frontiers of knowledge, regardless of where the work is conducted.

Universities depend on federal funding for most of the research carried out by their faculty and students, thus continuing the federal GU partnership that was established during World War II and expanded into the civilian realm thereafter. But in more recent decades, a number of policy issues have emerged that limit the effectiveness of the partnership. These issues, described in studies such as the National Academies NRC report *Research Universities and the Future of*

87. National Human Genome Institute, "About NHGRI: A Brief History and Timeline," http://www.genome.gov/10001763.

88. T. Aaltonen et al., "Evidence for a Particle Produced in Association with Weak Bosons and Decaying to a Bottom-Antibottom Quark Pair in Higgs Boson Searches at the Tevatron," *Physical Review Letters* 109 (7) (2012): 071804.

89. The United States at the Large Hadron Collider, Particle Physics Discovery Horizon, "The Large Hadron Collider," September 2012, http://www.uslhc.us/files/factsheets/large_hadron_collider.pdf.

90. Space Telescope Science Institute, "Hubble Space Telescope: HST Overview," June 21, 2010, http://www.stsci.edu/hst/HST_overview.

America[91] (see Focus Section B, page 46), include policies and practices that are viewed by university researchers and administrators as burdensome, inefficient, and costly, and that vary without apparent justification from agency to agency. Universities also argue that the administrative overhead allowed by the OMB does not cover the cost of managing federal research grants and dealing with an ever-increasing compliance burden.

At the same time, the nation's universities, especially its public universities, are facing a "perfect storm" of steadily decreasing state support combined with increasing requirements and expectations; pushback from parents on tuition increases; flat or decreasing federal research funding; and overhead rates that fall short of paying the full cost of federally funded research. Increased regulations and requirements that add to the administrative workload of university staff and administrators, and often evolve into unfunded mandates, have also made it increasingly difficult for universities to work with the federal government. On top of this, faculty are required to spend increasing amounts of time writing proposals for dwindling federal funds, submitting progress reports, reviewing proposals of colleagues that have little chance of being funded, attending study review sections, and focusing on additional administrative tasks that take time away from both research and teaching. Though some have argued that the nation has too many researchers, it would be far more accurate to state that certain fields have more researchers than the nation has elected to support.

Federal Government

The federal government is a major supporter of research and the largest supporter of basic research, especially that which is performed in universities. Thus, federal S&T policy largely determines what research gets done, how much gets done, and by whom. While there has been no overarching S&T policy, this system nonetheless had worked well for most of U.S. postwar history. It does not work well today.

The federal agencies that support research have their own challenges: budget fluctuations and unpredictability of future funding; the challenge of long-term planning with uncertain funding; unfunded mandates and increased pressure to do more with less from Congress; low success rates for research proposals; a stressed peer-review system; and high costs of modern research instruments and facilities. These problems have grown out of the decades of complacency and more recent stark shifts in national priorities away from long-term investments that followed the nation's past successes in building a national science and engineering research capacity of uncontested international prominence. The result is that much of the nation's research talent is underutilized, if not demoralized and simply wasted.

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91. National Research Council, *Research Universities and the Future of America*.

The federal government also funds research in its intramural laboratories.[92] Most of these laboratories and centers were created during or shortly after World War II to satisfy various national needs in defense, energy, health, space science and exploration, measurement standards, weather, agriculture, transportation, environmental protection, and other areas. Many of these laboratories work with universities by operating major research instruments – particle accelerators, synchrotrons, nuclear reactors, telescopes, supercomputers, high-magnetic field facilities – and providing access to difficult locations (such as NASA's share of the International Space Station and the NSF-funded Antarctic Program, which runs the Palmer Station, McMurdo, and South Pole research facilities). One long-running model of GU cooperation is JILA (formerly Joint Institute for Laboratory Astrophysics) at the University of Colorado, Boulder, which hosts the Quantum Physics Division of the National Institute of Standards (NIST) alongside university laboratories, and which has garnered three of NIST's four Nobel Prizes in Physics.[93] NIST works directly with industry in setting standards as well as through programs like the Technology Innovation Program (TIP), which was defunded in FY 2012, and the Hollings Manufacturing Extension Partnership (MEP).[94]

The federal government encourages industry to invest in R&D through the R&E Tax Credit,[95] though the credit has not been made permanent, as has been recommended by PCAST,[96] the National Academies,[97] and other organizations. It also offers little incentive to small and medium-sized companies, and it has no provision to encourage collaboration with universities or federally funded laboratories or centers. The R&E Tax Credit is an important policy that encourages companies to invest in R&D, and it thereby contributes to America's leadership position in science, engineering, and technology; but in its present form, it is not an effective mechanism to foster a robust GUI partnership.

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92. *Intramural laboratories* here refers to all of the national laboratories, including DOE's national weapons and general-purpose laboratories, NIH intramural laboratories, NOAA laboratories, NIST laboratories, NASA centers, and others.

93. With respect to NIST employees, Nobel Prizes in physics have been awarded to William D. Phillips (1997), Eric A. Cornell (2001), John L. Hall (2005), Dan Shechtman (2011), and David J. Wineland (2012). Cornell, Hall, and Wineland were all part of the Quantum Physics Division. Shechtman conducted a critical part of his prize-winning research while on sabbatical at NIST between 1981 and 1983. See JILA, "About JILA," JILA Science, http://jila.colorado.edu/about/about-jila.

94. Matt Hourihan, "Other Selected Agencies (Commerce, DOT, Interior, EPA, VA)," *AAAS Report XXXVII: Research and Development FY 2013* (New York: American Association for the Advancement of Science, 2012).

95. Gary Guenther, "Research Tax Credit: Current Law, Legislation in the 112th Congress, and Policy Issues," Congressional Research Service, November 29, 2011.

96. President's Council of Advisors on Science and Technology, *Transformation and Opportunity*.

97. Institute of Medicine et al., *Rising Above the Gathering Storm*.

State Governments

The states support research – indirectly – through their support of state universities. But in recent decades, states have been reducing their contributions to the total budgets of their public universities, in some cases dropping below 10 percent of the operating budgets.[98] The downward slide in state support has resulted in a pronounced need to find efficiencies and raise revenues from other sources such as tuition, fees, private donations, and funding from business, industry, and federal agencies. The recent substantial tuition increases at most public universities are a response to this financial pressure. Those universities unable to generate a richer revenue stream must make cuts to infrastructure, staff, financial aid, programs, and services. If they cut too deeply, they will be unable to compete with other institutions in the United States and around the world for the top students and faculty, as well as for federal research grants. Many state universities are therefore facing an uncertain future.

In addition to appropriations that support their universities, many states have created special funds to enhance research support, such as the Texas Emerging Technology Fund, a $485 million fund created by the Texas Legislature to advance the research, development, and commercialization of emerging technologies;[99] NYSTEM, a $600 million New York State initiative to support stem cell research;[100] or the California Institute for Regenerative Medicine (CIRM).[101] States also provide matching funds for some federal programs, such as EPSCoR (Experimental Program to Stimulate Competitive Research), which provides funding to help eligible states build capacity in science and engineering research.[102] In other cases, states provide a policy environment that encourages private investment in research parks, such as Research Triangle Park in North Carolina, where faculty and students from nearby universities (Duke University, North Carolina State University, UNC-Chapel Hill, North Carolina Central University) can engage with industry collaborators.

Business and Industry

Industry is the major supporter of U.S. R&D, primarily through applied research and product development focused on the needs of its business operations and paid for by business revenues.

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98. The Chronicle of Higher Education, "25 Years of Declining State Support for Public Colleges," March 3, 2014, http://chronicle.com/article/25-Years-of-Declining-State/144973?cid=megamenu.

99. The State of Texas Office of the Governor "Texas Emerging Technology Fund," http://governor.state.tx.us/ecodev/etf/.

100. New York State Stem Cell Science (NYSTEM), http://stemcell.ny.gov/.

101. California Institute for Regenerative Medicine (CIRM), http://www.cirm.ca.gov.

102. National Science Foundation, Office of International and Integrative Activities, "Experimental Program to Stimulate Competitive Research," http://www.nsf.gov/od/iia/programs/epscor/nsf_oiia_epscor_index.jsp.

Industry has also been a major performer of federally funded R&D for government agencies (see Focus Section C, page 67), especially the DOD. While the focus of business has always been on the perceived needs of its customers, in prior decades, companies generally took a longer-term view that demanded a substantial amount of basic research. Industry maintained a number of central research laboratories, including those supported by Bell Telephone, Xerox, General Electric, General Motors, Westinghouse, Texas Instruments, Hewlett Packard, Pfizer, Merck, and others. A number of Nobel Prizes were awarded for work done in these laboratories – particularly Bell Labs[103] – but these great industrial laboratories have since been dismantled or significantly downsized.

American companies today – most of them lacking large central research operations and some of them, including those in the pharmaceutical sector, having considerably reduced their R&D activity – have formed collaborations with universities and national laboratories that over time could develop as a national partnership. But there are still barriers that require our attention, including policies on intellectual property, management of potential conflicts of interest, and publication restrictions. Policy adjustments within both universities and companies could make these collaborations more attractive to both sectors, but industry still funds less than 5 percent of the nation's academic research.[104] While this contribution could grow, American companies have their own challenges as they try to compete in a rapidly changing global economy in which other countries boast lower labor costs and comparable or higher skill levels than the United States, as well as much more supportive tax and regulatory policies. Continuing to move people and facilities offshore will not help build an American GUI research partnership. Moreover, today's business culture does not reward long-term investment, making it hard to argue successfully for increases in R&D, especially research collaboration with universities.

The Future of the GUI Partnership

These and related issues constitute serious barriers to cooperation between universities, government, and industry. Some of the problems are small and could be solved without perturbing the system in any significant way. Others are systemic and reflect attitudes and cultures that have evolved over many decades. Collectively, they are impediments that prevent the kind of GUI partnership the nation will need if it is to retain a position of leadership in science and engineering research, and support the needs of its citizens.

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103. The following Bell Laboratories researchers have been awarded shared Nobel Prizes in Physics: Clinton J. Davisson (1937); John Bardeen, Walter H. Brattain, and William Shockley (1956); Philip W. Anderson (1977); Arno A. Penzias and Robert W. Wilson (1978); Steven Chu (1997); Horst Störmer, Robert Laughlin, and Daniel Tsui (1998); and Willard S. Boyle and George E. Smith (2009).

104. National Science Board, *Science and Engineering Indicators 2014*.

These few paragraphs cannot adequately describe the thousands of ways the federal and state governments, public and private universities, and companies (large and small) could collaborate in advancing the nation's science, engineering, and technology enterprise. With relatively modest changes in policies and practices in all sectors and some not-so-modest changes in attitudes and cultures, this enterprise could be substantially strengthened, placing the United States on a path to occupy again a leadership role in science, engineering, and technology. But this will not happen without a vision, an agreement among all stakeholders on where the nation needs to go and how to get there. It is the federal government's role, meanwhile, to create and implement a national science and technology policy that can be used as a strategic compass to guide the myriad policy decisions – budgets, priorities, regulations, programmatic changes – that are currently made largely without any consideration of long-term national goals.

Philanthropy and Science

The contributions of private foundations and philanthropy to scientific research have a long history and are of vital importance today. Andrew Carnegie and John Rockefeller were early leaders in philanthropic investment in research in the late nineteenth and early twentieth centuries. They established foundations, supported research, and created institutions devoted to advancing knowledge that are still prominent today. In 1917, Congress passed the War Revenue Act, which encouraged private giving by providing income tax deductions for donations to charitable, religious, scientific, educational, and other select organizations.[105] In more recent decades, Carnegie and Rockefeller were joined by such philanthropists as William M. Keck, Gordon Moore, Alfred P. Sloan, William Hewlett, David Packard, Arnold Beckman, Fred Kavli, Howard Hughes, and George P. Mitchell. An even newer generation of wealthy Americans – Bill Gates (Microsoft), Eric E. Schmidt (Google), Lawrence J. Ellison (Oracle), Paul Allen (Microsoft), Michael R. Bloomberg (Bloomberg News, former mayor of New York City), James Simons (hedge funds), and David H. Koch (oil, chemicals), among many others – are continuing the long tradition of philanthropy initiated by Carnegie and Rockefeller over a hundred years ago.[106]

105. Roy G. Blakey, "The War Revenue Act of 1917," *The American Economic Review* 7 (4) (1917): 791 – 815.

106. W. J. Broad, "Billionaires with Big Ideas are Privatizing American Science," *The New York Times*, March 15, 2014, http://www.nytimes.com/2014/03/16/science/billionaires-with-big-ideas-are-privatizing-american-science.html?_r=0.

Universities are also able to raise substantial amounts of money, usually through aggressive fundraising campaigns.[107] Much of this money is spent on new buildings, well-developed research instrumentation, and endowed professorships, fellowships, and scholarships; all of which contribute to the institutions' stature, infrastructure, and ability to provide a quality education and supportive learning environment. This funding also boosts universities' recruitment of top faculty, in turn enabling them to attract external funding to support research. In this way, private giving leverages research funding from government and industry.

Private giving by individuals, families, and foundations, as well as by university alumni, is likely to be an increasingly important source of research funding, especially in medical research and other fields of science that continue to arouse the public's interest. But as today's philanthropists themselves point out, philanthropy is not a substitute for funding from government and industry.[108] Companies will support research that is important to their products or services and that can be justified to stockholders. Similarly, state governments will support research with downstream impacts on economic development or other local interests. Federal agencies not only support research vital to their own missions – including defense, energy, health, environmental protection and conservation, agriculture, climate and weather prediction, transportation, and space science and exploration – but also fundamental, discovery-driven basic research. Basic research is often performed with the hope that the results may be important in some future applications; but at its core, it is an exploratory, even risky endeavor, which is why industry invests so little in it. Further, the benefits derived from basic research often are not the property of the funder or researcher, but are enjoyed by society as a whole. The purpose of basic research is to question existing theories and expand the frontiers of knowledge: researchers must be ready for surprises and have the will and flexibility to follow unexpected outcomes. This is the process of producing major discoveries that in turn lead to revolutions in understanding, breakthrough technologies, the creation of jobs, and improved health for broad elements of society.

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107. Council for Aid to Education, "Colleges and Universities Raise $33.80 Billion in 2013," Press Release, February 12, 2014.

108. Ibid.

U.S. SCIENCE AND TECHNOLOGY POLICY: TIME FOR AN UPGRADE

In his 1945 report *Science, The Endless Frontier*, Vannevar Bush offers the following observations about national science policy:

> We have no national policy for science. The Government has only begun to utilize science in the nation's welfare. There is no body within the Government charged with formulating or executing a national science policy. There are no standing committees of the Congress devoted to this important subject. Science has been in the wings. It should be brought to the center of the stage – for in it lies much of our hope for the future.[109]

While few if any U.S. presidents have placed science at the center of their agenda, nearly all recent presidents have seen value in having a science advisor, and sometimes a science advisory committee, to whom they can turn for objective advice on matters relating to science. Every President since Franklin D. Roosevelt has employed such an advisor in the White House, either reporting directly to him (Assistant to the President) or to someone close to the President (Special Assistant to the President).[110] The Nixon administration represents the one exception, since President Nixon eliminated the President's Science Advisory Committee (PSAC) over policy disagreements, and his science advisor subsequently resigned.[111] On that occasion, the director of the NSF, Guyford Stever, was asked to take on additional responsibilities and was ultimately brought to the White House as science advisor by President Gerald Ford following Nixon's resignation.[112]

Congress, unhappy with these events, passed the National Science and Technology Policy, Organization, and Priorities Act of 1976, setting up the Office of Science and Technology Policy, with a director to be appointed by the President and confirmed by the Senate.[113] The mission of the OSTP, as stated in the 1976 act, is to "serve as a source of scientific and technological analysis and judgment for the President with respect to major policies, plans, and programs of the federal government." Since Stever's time, the director of the OSTP has concurrently served as the President's science advisor. Several presidents have also appointed advisory commit-

109. Bush, *Science, The Endless Frontier*, 7.

110. Roger Pielke and Roberta A. Klein, *Presidential Science Advisors: Perspectives and Reflections on Science, Policy and Politics* (New York: Springer, 2010).

111. Richard D. Lyons, "Science Adviser to Nixon Leaving for Industry Job," *The New York Times*, January 3, 1973.

112. T. Kenneth Fowler, *H. Guyford Stever, 1916 – 2010* (Washington, D.C.: National Academy of Sciences, 2010).

113. *National Science and Technology Policy, Organization, and Priorities Act of 1976*, Public Law 94-282, H.R. 10230, 94th Congress (May 11, 1976), http://www.gpo.gov/fdsys/pkg/STATUTE-90/pdf/STATUTE-90-Pg459.pdf.

tees: PSAC in the early years and PCAST since the George H. W. Bush Administration.[114] A science advisor's influence depends on many factors: the priorities and interests of a particular President, world events, and the extent to which important policy issues require scientific or technical information. During the early years of the Cold War, the space race, and the nuclear standoff with the Soviet Union, the nation's priorities were clear. The Soviet launch of Sputnik I and II compelled President Eisenhower to seek expert scientific advice. His science advisor, James Killian, and his advisors on PSAC, most of whom were physicists, were heavily involved in a number of key administrative decisions.[115] As the Cold-War political system dissolved, presidents' priorities became less focused on particular matters requiring scientific or technical expertise (such as bombs, rockets, and satellites) and the job of advising the President became more diffuse. Increasingly, science and technology were a part of day-to-day government life, and the science advisor was expected to be able to cover the broad landscape, ensuring that the President was informed on all related matters – in national defense, health, energy, transportation, agriculture, environmental protection, commerce, human space travel, and so forth. The OSTP was thus expected to coordinate science and technology activities across all federal agencies.

The OSTP is today the one office in the federal government that considers overall national science and technology policy when offering advice to the President. Each incoming President lays out a set of science and technology priorities (along with broad policy priorities) with which the administration's actions, including budget requests, are generally consistent. In recent administrations, the director of the OSTP and director of the OMB have sent a letter to the agencies early in the budget preparation cycle, stating the President's priorities, at least in general terms. Presidents have also launched special initiatives that underscore those priorities. For example, President Clinton's National Nanotechnology Initiative (NNI) was included in his FY 2001 budget request.[116] The idea for the NNI came out of a growing body of research from across the country focused on nanometer-scale materials and the desires of several federal agencies to increase and coordinate their efforts to ensure that the United States had a leadership position in this important emerging field. An interagency plan was presented to the members of PCAST for their review and comment. The science advisor and other members of PCAST recommended it to the President, who included it in his budget. The Clinton initiative led to the 21st Century Nanotechnology Research and Development Act, signed into

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114. Executive Order No. 13226, *President's Council of Advisors on Science and Technology*, Title 3, 66 Federal Register 192 (October 3rd, 2001).

115. James Killian, *Sputnik, Scientists and Eisenhower: A Memoir of the First Special Assistant to the President for Science and Technology* (Cambridge, Mass.: MIT Press, 1977).

116. Committee on Technology, National Science and Technology Council, *A Report by the Interagency Working Group on Nanoscience, Engineering, and Technology* (February 7, 2000).

law in 2003 by President George W. Bush.[117] The NNI continues to be a priority more than a dozen years after its creation.

The NNI demonstrates that the United States possesses the ability to launch long-term science and technology efforts and funding in focused areas. The U.S. Global Change Research Program, an initiative of President George H. W. Bush, is an even earlier example; and President Obama's multiagency BRAIN Initiative (Brain Research through Advancing Innovative Neurotechnologies), led by the NIH, is the most recent.[118] However, Vannevar Bush would still be correct in stating that the United States has no national science policy.[119] There is no science and technology planning mechanism in Congress. Authorization committees may come the closest, but their bills are constrained by jurisdictional boundaries. One could imagine a joint committee, or separate committees of the House and Senate, focused on national science and technology and the U.S. research enterprise. The President's science advisor and the OSTP could work with such a committee to seek areas of agreement between the President and Congress on nonpartisan matters. In principle, such an arrangement could produce a long-range national science and technology policy that has bipartisan support and could be visited and revised as necessary by future presidents and Congresses.

Vannevar Bush envisioned that such a mechanism would be needed. He recommended an advisory body that would advise both the executive and legislative branches:

> In the Government the arrangement whereby the numerous scientific agencies form parts of larger departments has both advantages and disadvantages. But the present pattern is firmly established and there is much to be said for it. There is, however, a very real need for some measure of coordination of the common scientific activities of these agencies, both as to policies and budgets, and at present no such means exist.
>
> A permanent Science Advisory Board should be created to consult with these scientific bureaus and to advise the executive and legislative branches of Government as to the policies and budgets of Government agencies engaged in scientific research.[120]

Bush might be surprised to find that seventy years later we still have no such mechanism within the government. In the executive branch, the White House partially addresses this need

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117. *21st Century Nanotechnology Research and Development Act of* 2003, Public Law 108-153, S. 189, 108th Congress (December 3, 2003), http://www.whitehouse.gov/files/documents/ostp/Issues/Nano%20Act%20 2003.pdf.

118. Office of the Press Secretary, "Remarks by the President on the BRAIN Initiative and American Innovation," The White House, Washington D.C., April 2, 2013, http://www.whitehouse.gov/the-press -office/2013/04/02/remarks-president-brain-initiative-and-american-innovation.

119. Bush, *Science, The Endless Frontier*, 7.

120. Ibid., 15.

through the National Science and Technology Council, a cabinet-level committee chaired by the President that includes heads of research agencies (the NSF, NIH, and NIST, among others) and works with the OSTP to coordinate interagency activities, such as the aforementioned NNI.[121] The real work of the NSTC is carried out by several coordinating committees. PCAST provides advice to the President, but it also produces public reports on important issues of S&T policy and, in this way, provides advice to Congress. Yet there is no committee or board filling the need that Bush highlighted in his report in 1945.

The lack of a mechanism in Congress to address national science and technology issues and to coordinate policy with the President remains a major policy issue. In the past, Congress had its own agency, the Office of Technology Assessment (OTA), which offered members and committees objective and authoritative views of complex scientific and technical issues.[122] The job of the OTA was not to establish a national science and technology policy, but the agency's authoritative analysis was critical to legislative decision-making related to science and technology. The OTA was internationally renowned and formed a model that other countries have followed with considerable success. The OTA remains authorized, but it has not had an appropriation since it was defunded by Congress at the end of September 1995, following twenty years of service.[123] The Congressional Research Service (CRS) has a Division of Resources, Science, and Industry that provides policy analysis for members and committees, but it has a broad mandate and lacks the resources to focus on scientific and technical issues, which increasingly connect with many areas of national policy.[124] Some members of Congress have recognized the need for this kind of expert advice and have tried to reinvigorate the OTA's funding, but so far these efforts have been unsuccessful.

The separation of powers laid out in the U.S. Constitution and by American political philosophies and practices that have evolved since the nation's founding make long-range planning difficult on any policy matter. But the importance to America's future of the nation's standing in SE&T – with research at its root – and the key roles of the federal and state governments, universities, business and industry, and philanthropy are matters that ought to transcend

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121. Executive Order No. 12881, *Establishment of the National Science and Technology Council*, Title 3, Section 301, 58 Federal Register 226 (November 23, 1993).

122. *Technology Assessment Act of 1972*, Public Law 92-484, H.R. 10243, 92nd Congress (October 13, 1972), http://www.gpo.gov/fdsys/pkg/STATUTE-86/pdf/STATUTE-86-Pg797.pdf.

123. Bruce Bimber, *The Politics of Expertise in Congress: The Rise and Fall of the Office of Technology Assessment* (New York: SUNY Press, 1996).

124. The CRS carries out policy research and analysis in American law, domestic social policy, foreign affairs, defense and trade, and government and finance, in addition to the work of its resources, science, and industry division (see Library of Congress, "Resources, Science and Industry Division," Congressional Research Service, http://www.loc.gov/crsinfo/research/div-rsi.html).

political dissent. Science and technology policy in all sectors is in need of revitalization and restructuring; chapter three of this report outlines a number of steps that, if implemented, will lead to progress.

> *"Science, like any field of endeavor, relies on freedom of inquiry; and one of the hallmarks of that freedom is objectivity. Now, more than ever, on issues ranging from climate change to AIDS research to genetic engineering to food additives, government relies on the impartial perspective of science for guidance."*
>
> – President George H. W. Bush, April 23, 1990[125]

125. George H. W. Bush, "Remarks to the National Academy of Sciences," April 23, 1990, The George Bush Presidential Library and Museum, http://bushlibrary.tamu.edu/research/public_papers.php?id=1790&year=1990&month=4 (accessed September 2, 2014).

FOCUS SECTION C

New Perspectives on Technology Transfer and University-Industry Partnerships

"In conquering the frontier [of high technology] we cannot write off our traditional industries, but we must develop the skills and industries that will make us a pioneer of tomorrow."

– President Ronald Reagan, January 25, 1983,
Address Before a Joint Session of Congress on the State of the Union[126]

Early History and Rationale

The federal government is the primary source of funding for basic research, and universities (including university medical schools) perform 55 percent of all U.S. basic research.[127] In 2011, federal agencies supported about $36 billion in university research,[128] an investment that not only creates new knowledge and new discoveries, but also lays a foundation for new products and processes that energize the economy and improve the lives of millions of Americans. There is also human capital benefit, since university research educates the next generation of science leaders.

In order to bring the benefits of federally funded university research to society, universities strive to transfer the results of that research – including knowledge and people – to outside of the university. While universities and other nonprofit organizations have the ability to patent inventions born out of federally funded research,[129] they must offer to license these inventions to industry and business (especially small businesses) for commercial development.[130] Strategies for exploiting intellectual property for which there is a commercial interest are generally managed by university technology transfer offices (TTOs). Five primary objectives are commonly shared among TTOs: 1) disseminate new knowledge; 2) advance regional economic development; 3) serve university faculty; 4) build goodwill among potential future donors; and 5) generate revenue for the institution and the inventor.[131]

Before 1980, this was not the case. The federal government retained title to any invention developed in a federal or university laboratory, or that otherwise grew out of research that had been funded by the federal government. At the time, the federal government would only grant nonexclusive licenses to patents, a risky and unattractive approach to most companies.

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126. Ronald Reagan, "Address Before a Joint Session of Congress on the State of the Union," January 25, 1983, *The American Presidency Project*, http://www.presidency.ucsb.edu/ws/?pid=41698.

127. National Science Board, *Science and Engineering Indicators 2014*.

128. Ibid.

129. The federal government also receives a nonexclusive, irrevocable license to that invention.

130. Association of American Universities, "Understanding University Technology Transfer," January 2011.

131. National Research Council, *Managing University Intellectual Property in the Public Interest*.

By 1978, fewer than 4 percent of the 28,000 patents acquired by the federal government had been licensed.[132]

Economic stagnation in the 1970s, exacerbated by the eroding U.S. steel and automotive markets,[133] sparked a series of legislative debates in Congress to identify ways to promote private-sector development and utilization of federally funded research. By 1980, the federal investment in R&D totaled $62.8 billion (in constant 2005 dollars), leading to the development and translation of many new technologies that greatly benefitted Americans.[134] But many in Congress believed that there existed opportunities for an even greater technology transfer model and private sector engagement. In particular, members of Congress believed collaboration between the universities and the business community, especially small businesses (which can be more fiercely innovative than larger companies), could be improved upon to leverage fully all components of the national R&D enterprise.[135]

The 1980 University and Small Business Patent Procedures Act, sponsored by Senators Birch Bayh (Democrat, Indiana) and Bob Dole (Republican, Kansas) and commonly referred to as the Bayh-Dole Act, effectively allowed for universities and other nonprofits to claim ownership rights to inventions that had been designed in university development labs but that had been funded with federal money.[136] Overall, the successes of the Bayh-Dole Act have surpassed expectations, although it still has its critics. But since a great deal of flexibility was purposefully built into the Bayh-Dole Act, many of the issues pointed to today as negative outcomes are actually the result of separate institutional policies.[137]

Before 1980, only twenty-three universities had TTOs, yet today every major university has some form of technology transfer system or an office of technology licensing (OTL). Although the profitability of today's university TTOs varies greatly, the creation of these offices and their resulting technology developments have sparked a new wave of start-up companies. In turn, these start-ups provide new job opportunities and introduce new products to the consumer market. From 1996 to 2007, university-licensed products created more than 279,000 jobs, and

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132. Vicki Loise and Ashley J. Stevens, "The Bayh-Dole Act Turns 30," *Science Translational Medicine* 6 (2010), doi:10.1126/scitranslmed.300148, http://stm.sciencemag.org/content/2/52/52cm27.full.

133. Howard Markel, "Patents, Profits, and the American People – The Bayh-Dole Act of 1980," *The New England Journal of Medicine* 369 (2013): 794–796.

134. Wendy H. Schacht, "The Bayh-Dole Act: Selected Issues in Patent Policy and the Commercialization of Technology," Congressional Research Service, March 16, 2012.

135. Ibid.

136. Loise and Stevens, "The Bayh-Dole Act Turns 30."

137. Sara Boettiger and Alan B. Bennett, "Bayh-Dole: If We Knew Then What We Know Now," *Nature Biotechnology* 24 (3) (2006): 320–323.

academic technology transfer contributed more than $187 billion to the U.S. economy.[138] Technology transfer is also a large part of IP-intensive industries, which, according to a U.S. Development of Commerce report released in 2012, supports forty million U.S. jobs and contributes $5 trillion to the economy, or 34.8 percent of U.S. domestic product.[139]

University Challenges

For universities, early rationales for taking on the immense task of building up internal infrastructure to support technology transfer were heavily based on the perceived potential to generate revenue for the university. In reality, this growth has presently only been experienced by a few universities, including MIT, Stanford University, University of Wisconsin, and Columbia University. In 2012, the top eight universities collected half of the total licensing income of the entire university system; the top ten took 70 percent of the total. High returns tend to be the result of one blockbuster patent. Consequently, only 16 percent of university TTOs are currently self-sustaining.[140]

One criticism of university ownership of IP is that universities become tied to the process of maximizing financial gains from their licensing holdings, despite the costliness of managing patent portfolios, which includes meeting TTO staffing needs and employing lawyers for complicated licensing negotiations.[141] Universities widely recognize that the revenue produced over time by patent portfolios is widely variable and requires a long-term commitment, and many have begun to shift their expectations toward a focus on improved UI partnership, benefits to the local economy, the development of new businesses,[142] and the creation of loyal faculty and students.

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138. Loise and Stevens, "The Bayh-Dole Act Turns 30."

139. Economic and Statistics Administration and United States Patent and Trademark Office, *Intellectual Property and the U.S. Economy: Industries in Focus* (Washington, D.C.: U.S. Department of Commerce, 2012).

140. Walter D. Valdivia, *University Start-Ups: Critical for Improving Technology Transfer* (Washington, D.C.: Brookings Institute/Center for Technology Innovation at Brookings, 2013), 6 – 15.

141. Heidi Ledford, "Universities Struggle to Make Patents Pay: Surfeit of Unlicensed Intellectual Property Pushes Research Institutions into Unseemly Partnerships," *Nature* 501 (2013): 471.

142. Boettiger and Bennett, "Bayh-Dole: If We Knew Then What We Know Now."

Nine Points to Consider in Licensing University Technology

Reproduced from National Research Council, *Managing University Intellectual Property in the Public Interest* (Washington, D.C.: The National Academies Press, 2010).

1. Universities should reserve the right to practice licensed inventions and to allow other nonprofit and governmental organizations to do so.
2. Exclusive licenses should be structured in a manner that encourages technology development and use.
3. Strive to minimize the licensing of "future improvements."
4. Universities should anticipate and help to manage technology transfer–related conflicts of interest.
5. Ensure broad access to research tools.
6. Enforcement action should be carefully considered.
7. Be mindful of export regulations.
8. Be mindful of the implications of working with patent aggregators.
9. Consider including provisions that address unmet needs, such as those of neglected patient populations or geographic areas, giving particular attention to improved therapeutics, diagnostics, and agricultural technologies for the developing world.

Endorsing "consideration" of the Nine Points, AUTM [the Association of University Managers] urged its individual members to seek their institution's endorsement of the document by whatever internal decision-making processes are used. AUTM continues to seek endorsements of the document. As of January 2010, only 74 of AUTM's member institutions had signed on.

But universities are not one-size-fits-all. University experiences with the success and profitability of technology transfer will depend on the type of institution, the size of the institution, the breadth and focus of their research portfolio, the level of engagement with states, and their relationship with local businesses. For example, public universities are the least likely to achieve a large pay-off – the University of California system and University of Wisconsin being notable exceptions – yet are often pressed by their boards to raise revenue through technology transfer with the goal of growing self-sustaining TTOs. Another set of challenges facing universities and TTOs lies in their relationships with industry and the business community. Certain barriers to UI partnerships are ingrained in institutional cultures. While the private sector is nimble and focused on shareholders, universities are generally slowed by internal bureaucracy and work to advance a mission that benefits the public. No one solution exists, although many universities strive to adhere to common best practices. In addition, a number of institutions have begun to take strides toward new models for technology transfer that may serve as a template for other similar institutions.

Experimental Frameworks

Pennsylvania State University

Penn State recently developed a seven-point plan to be implemented within two years (see sidebar, page 72), designed to make the university a model for open innovation while also returning to its core mission of performing research and disseminating knowledge for the betterment of society. Penn State observed that over a period of thirty years, roughly one-quarter of its opportunities to openly collaborate and innovate with industry were lost because the university would not establish a license cost until the invention had been demonstrated and valued by the market – an arrangement that was unsatisfactory to many potential partners in industry. Penn State has concluded that ownership of IP, which is upstream of this hurdle, is less valuable than the potential to engage in more industry-sponsored research.[143]

Carnegie Mellon University

Carnegie Mellon fundamentally changed the way it approaches technology commercialization. The university deemphasized revenue generation and created a process dubbed by former CMU Provost Mark Kamlet as the "5 percent and go in peace" policy, which eliminated or greatly reduced the need for faculty to negotiate with the institution. These changes and enhancements to the University's entrepreneurial programs produced a dramatic increase in company creation and faculty satisfaction with the process.[144]

University of Minnesota

University of Minnesota's Minnesota Innovation Partnerships (MN-IP) aim to increase the business community's access to technologies developed at the university. Composed of two parts – MN-IP Create and MN-IP Try and Buy – the program grants companies exclusive license to IP resulting from industry-sponsored research conducted at the University of Minnesota. It also establishes pre-set licensing terms and allows companies to engage in a low-cost "test run" of an innovation to reduce risk.[145]

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143. Henry C. Foley, "A New Approach to Intellectual Property Management and Industrially Funded Research at Penn State," *Research Technology Management* (September – October 2012): 1 – 6.

144. Louise Anderson et al., "Creating Quality Jobs: Transforming the Economic Development Landscape," International Economic Development Council, March 2010, 151.

145. "For Industry: Minnesota Innovation Partnerships," University of Minnesota Office for Technology Commercialization, http://www.research.umn.edu/techcomm/industry-sponsor.html#.U8Qo-PldXTo.

Penn State's Seven-Point Plan for Reinvigorating the Research Culture

Reproduced from Henry C. Foley, "A New Approach to Intellectual Property Management and Industrially Funded Research at Penn State," *Research Technology Management* (September–October 2012): 1–6.

1. Create an Office of Technology Management, uniting functions now performed by the Industrial Research Office and the Intellectual Property Office.
2. Spur growth in industry-funded research with more flexible intellectual property policies.
3. Manage master agreements in a way that provides real value to the industry partner and to the university by building end-to-end partnerships.
4. Create a culture of entrepreneurship by creating more trust, ownership, and excitement among the faculty.
5. Raise revenue by selling off existing university-owned intellectual property.
6. Rename and explain the conflict of interest policy to encourage participation and better protect faculty members and the university.
7. Create the Techcelerator Innovation Center by collocating the new Small Business Development Center, the new Office of Technology Management, the Office of Sponsored Programs, and the Ben Franklin Technology Partners' Center with the New Business Incubator, the Innovation Park Management Office, and the Centre County Chamber of Business and Commerce.

What it Means for University-Industry Partnerships

Partnerships between universities and industry can benefit greatly from improved interactions and the overcoming of cultural barriers. By working to balance their interests with those of industry, universities can attract more private-sector research partnerships that help serve the university mission of creating new knowledge and technologies for the betterment of society. There are many examples of existing initiatives or consortiums designed to strengthen UI partnerships, some of which are highlighted here.

DOE Energy Hubs

The DOE's Energy Innovation Hubs are research centers that focus collaborative teams of researchers on tackling the development of a complete and integrated energy system based on transformative energy technologies and strong partnerships with industry.[146]

146. "Hubs," Department of Energy, http://energy.gov/science-innovation/innovation/hubs/.

STARTUP-NY

SUNY Tax-free Areas to Revitalize and Transform Upstate New York (STARTUP-NY) is an initiative to support and promote the creation of new businesses at SUNY campuses and other New York universities. Through this initiative, businesses located in designated zones will be able to operate completely tax-free for ten years and have access to university resources, while universities will expand access to business experiences for their students.[147]

NIH BEST

The NIH Director's Biomedical Research Workforce Innovation Award: Broadening Experiences in Scientific Training (BEST) is designed to support competitive universities in expanding student and trainee exposure to career options in or related to research, especially outside of the university setting. The awards cover up to $250,000 in annual direct costs for up to five years.[148] The first recipients were announced in the fall of 2013.[149]

147. STARTUP-NY, http://startup.ny.gov/.

148. "NIH Director's Biomedical Research Workforce Innovation Award: Broadening Experiences in Scientific Training (BEST)," Department of Health and Human Services, http://grants.nih.gov/grants/guide/rfa-files/RFA-RM-12-022.html.

149. "NIH Announces Awards to Strengthen the Biomedical Research Workforce," The National Institutes of Health, September 23, 2013, http://www.nih.gov/news/health/sep2013/od-23.htm.

CMU Practices to Facilitate Entrepreneurship

- **Encourage, but do not control, inventors**
  - Allow inventors to personally own their inventions (certain provisions may apply if developed with external funding)
  - Allow faculty to take on a leadership role in their start-up, while assisting in managing conflicts
- **Coach and challenge, but let the market decide**
  - Start-up–worthy projects are not determined by a "gatekeeper" mechanism
- **Offer transparent and supportive deal terms**
  - No upfront license fee, and no royalty accrual for three years
  - Standard start-up license: 6 percent equity/2 percent royalty for exclusive license
  - Option to "incubate" on campus for an additional 1 percent equity per year
  - Option to defer reimbursement of patent expenses for three years for additional equity
- **Support development and testing of technology concept, business strategy, and company roll-out**
  - Provisional patents are prepared in-house, lowering the barrier to initial protection and enabling market testing of the technology or idea
- **Provide support to facilitate technological advancement**
  - Gap funding program for market research and technology milestone achievements
  - Active mentorship and assistance in finding business partners
  - Strong ties with local groups for additional mentoring, gap funds, and pre-seed funds
  - Incubator for student start-up explorations
  - Workshops on entrepreneurial topics
  - Investment fund for alumni-launched start-ups
  - Fellowship program for graduate student participation in faculty start-ups

FOCUS SECTION D

A "Bell Labs 2.0" for Sustainable Energy

*Contributed by **Steven Chu** (William R. Kenan, Jr., Professor of Physics and Molecular & Cellular Physiology, Stanford University; former U.S. Secretary of Energy; former Director, Lawrence Berkeley National Laboratory) and **Arun Majumdar** (Jay Precourt Professor and Senior Fellow at the Precourt Institute for Energy, Stanford University; former Director, Advanced Research Projects Agency-Energy [ARPA-E], U.S. Department of Energy; former Vice President for Energy, Google)*

The era of great industrial research laboratories that took a long-term approach to science and engineering R&D and laid the technological foundations of the computing and communication revolution of the twentieth century is largely over. The size and scope of these institutions have been greatly reduced, diminishing a vital source of U.S. technological innovation in the process. Further, there is no industrial research laboratory in the United States devoted to addressing the critical global problems of the twenty-first century, such as building a sustainable energy future.

Research universities can partially fill this gap, but their research mission is interwoven with student training. Young professors at the start of their professional careers are asked suddenly to shift their focus from doing research to training students, and because the success rates of receiving federal funding are both low and decreasing, they spend an ever-growing fraction of their time writing grant proposals. Instead of continuing to hone their scientific skills, faculty become research administrators. Furthermore, the peer-review system is gravitating toward rewarding incremental proposals rather than high-risk but potentially transformative ideas.

National laboratories provide both a broad research base and world-class experimental facilities. Since their mission is not primarily educational, they are predominantly composed of professional staff scientists and engineers. Such laboratories, however, are often structured to reflect funding agency silos that reward basic science or applied technology, rather than provide a seamless integration of science and engineering and research and development. The national labs have also assumed a culture where scientific novelty and research publications are the predominant measure of success, and opportunities in multidisciplinary science and systems engineering are rarely seized.

A Lab For Sustainable Energy

From the 1930s through the 1990s, AT&T Bell Labs was at the pinnacle of the research areas it chose to support. We believe in creating a "Bell Labs 2.0" in select areas of sustainable energy that could have an impact on energy comparable to that which Bell Labs had on communications.

The success of any new research organization is critically dependent on the quality of the people hired and the culture established. We envision a head of the lab with a very flat management organization, in which all managers are eminent, practicing scientists and engineers. The leadership needs to have an extraordinary eye for talent and the ability to recruit the best people; such leaders would serve as the connective tissue between the lab and academia, national laboratories, and industry.

Within each department, there would be principal investigators (PI) who are given the freedom to set their research direction within the broad scope of the lab's mission. Each experimental PI could have at most two people (for example, one postdoctoral fellow and one technician) under his or her direct supervision, automatically encouraging collaboration among PIs. A small number of theoretical, mathematical, and computational scientists would round out the organization. Early-career scientists and engineers (the principals) and their postdoctoral fellows would form 80 to 90 percent of the staff. As was the Bell Labs experience, successful members of the technical staff seeking larger groups would be lured to other institutions. We would anticipate a minimum critical mass of perhaps 80 to 90 PIs and 160 to 200 total scientific staff (PIs, postdoctoral fellows, and technicians).

As with Bell Labs, there would be no tenure. The principal attraction to participants would be the quality of colleagues and the atmosphere in the lab. Scientists and engineers would not have to write proposals, teach, or be burdened by administrative committees. All funding would be internal and beyond a base level of funding, each director and department head would make informed and rapid decisions. Within the broad scope of the mission of the lab, each PI would receive start-up equipment funds and adequate operating funds. There should not be large "start-up" packages, but the technical staff would be secure in knowing that sufficient resources would be rapidly available to support great ideas.

The lab leadership should encourage the PIs to aim high as possible. By their very nature, many bold ideas will fail, and the PIs should be encouraged to try out new ideas quickly, with "multiple shots at goal." At the same time, the leadership must have enough cachet and courage to terminate funding for a project that does not meet the high expectations of the organization.

Funding, Intellectual Independence, and Connectivity

The lab should be an independent entity and not part of a university, national laboratory, or specific company. Otherwise, the mission and management practices could be eroded over time and aligned with the host institution. It should have financial independence through an endowment, which would ensure funding for great research ideas and their translation into technological innovations. For example, a $3 billion endowment will create a $150 million annual operating budget, which would form a critical, steady-state mass of 130 principals plus staff. All patents would belong to the lab, and licensing and royalty income from these patents would be reinvested in research.

The independence suggested here does not mean ivory-tower isolation. To have economic and societal impact, the Bell Labs 2.0 for sustainable energy must partner with the right institutions and businesses to develop opportunities for transitioning technologies from lab to market. Technology transfer is a contact sport, and the lab should be located in a rich intellectual ecosystem such as a major research university or national lab, or embedded in industrial and financial institutions. In such an environment, Bell Labs 2.0 could gain leverage from existing infrastructure and be a catalyst for greater intellectual and entrepreneurial fervor.

Chapter 3

Prescriptions for the Future Health of the Science and Engineering Research Enterprise

The disturbing trends highlighted in the executive summary, coupled with the challenges to the research enterprise described in chapters one and two, indicate that the health of the nation's research enterprise is failing, and that the United States is in danger of being overtaken by competitor nations that are rapidly advancing in SE&T. Prescriptions for reversing these trends must treat their causes, not merely the symptoms. The nation needs to develop a sustainable approach to research funding, as well as new mechanisms to enable long-term planning of its investments in research. In the face of political and economic realities, we must also make better use of existing resources by strengthening partnerships across federal and state governments, public and private universities, and industry and business.

This chapter presents three prescriptions to improve the health of the nation's science and engineering research enterprise: 1) secure America's leadership in science and engineering research – especially basic research – by providing sustainable federal funding and setting long-term investment goals; 2) ensure that the American people receive the maximum benefit from long-term federal investments in research; and 3) regain America's standing as an innovation leader by establishing a more robust national government-university-industry research partnership. The committee offers several specific actions that could be taken in the near future to help achieve each of these goals.

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

Behind every new product brought to market, every new medical device or drug, and every new defense and space technology, are years of patient investment in R&D by industry, government (federal and state), and universities. If the United States is to remain a leader in pioneering and producing these benefits to society, it must make the necessary investments.

The total U.S. investment (public and private) in R&D measured as a percentage of GDP – an accepted metric for the country's commitment to the future of its citizens – continues to fall short of the national goal of at least 3 percent adopted by several U.S. presidents, even as America's economic competitors move aggressively to increase their own investments in R&D (see Figure 7, page 79). America is falling behind in innovation by failing to make the investments needed for the United States to remain the global leader in industry and commerce.[150]

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150. United States Senate Committee on Appropriations, *Full Committee Hearing: Driving Innovation through Federal Investments*, April 29, 2014, http://www.appropriations.senate.gov/hearings-and-testimony/outside-witness-testimony-federal-innovation-hearing.

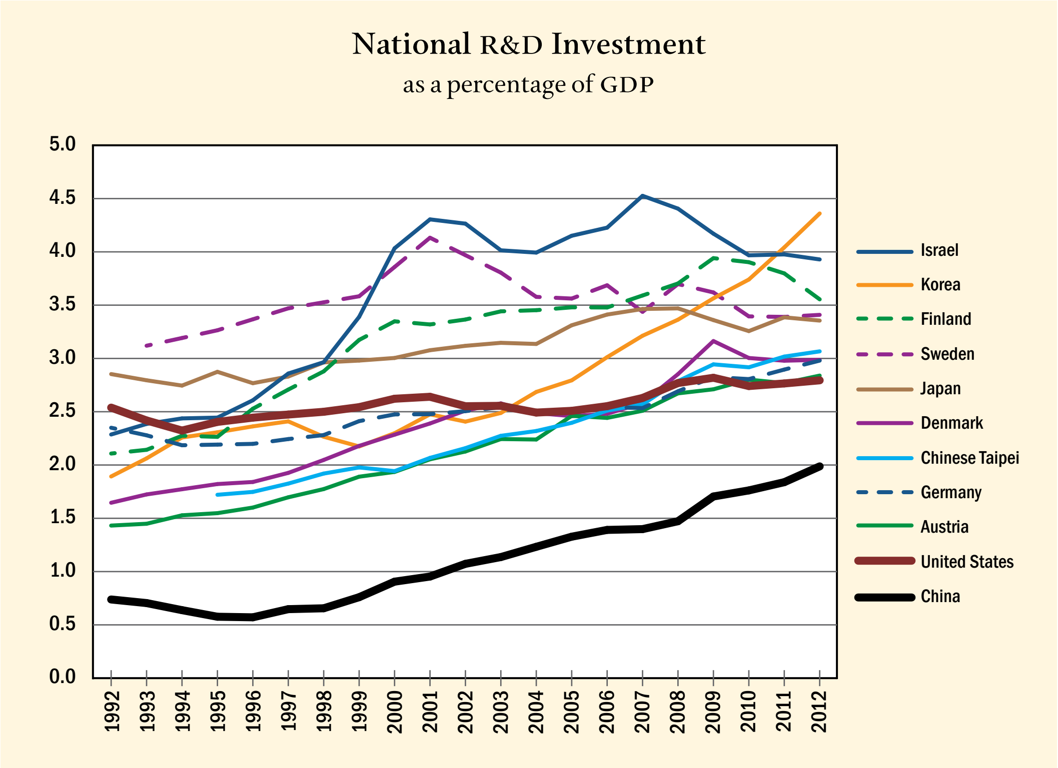

Figure 7

The United States is Failing to Keep Pace with Competitors' Investments in R&D

As China's R&D intensity (black) rapidly grows by an average of 8 percent per year in pursuit of the goal of R&D investment equal to 3 percent of GDP, U.S. investments (red) have pulled back. At this pace, China will surpass the United States in R&D intensity in about eight years.[151]

Source: Organisation for Economic Co-operation and Development, *Main Science and Technology Indicators*, vol. 2013, no. 2 (Paris: OECD Publishing, 2014), Table 2, "Gross Domestic Expenditures on R&D (GERD) as a Percentage of GDP."

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151. Ibid.

Establishing and maintaining a sustainable approach to American innovation will require increased investments (public and private) in R&D. Increasing the national goal for total R&D investment would not only signal to the rest of the world that the United States intends to remain a leader in innovation and industrial competitiveness, but would also provide our nation with the resources to continue to lead.

U.S. industry funds 63 percent and performs 69 percent of the nation's R&D, which primarily consists of applied research and development.[152] Most of America's innovations, as well as its quality jobs, are created in private industry. But companies depend on a continuous stream of new scientific discoveries and early-stage technologies that flow from the federal government's investments in research, particularly basic research, carried out at research universities and national laboratories.[153] Companies working closely with academic and government researchers benefit most from timely translation of research results into marketable applications and from early access to talented scientists and engineers trained largely at American universities.

Recapturing American competitiveness in innovation will require that federally funded research, particularly basic research, become a higher priority than it has been over the past two decades. From 1975 to 1992, the federal investment in basic research grew at an average annual inflation-adjusted rate of 4.4 percent (Figure 8, page 81), despite serious political and economic challenges, including the 1973 oil embargo, the Great Inflation of 1979 – 1982, and the final tumultuous years of the Cold War. During this period, Republicans and Democrats, in spite of a number of policy differences, were in agreement that federal funding of basic research was a priority for the nation.

Since that time, however, the nation's research funding has stagnated. As a function of U.S. economic output (as measured by GDP) federal support for basic research is actually *lower* than it was twenty years ago, and the federal investment is more than $13 billion below the trend established in the 1970s and 1980s (Figure 9, page 82). The doubling of the NIH budget and the American Recovery and Reinvestment Act of 2009 (ARRA) briefly restored the nation's historical commitment to basic research; however, in both cases the gains rapidly eroded.

152. National Science Board, *Science and Engineering Indicators 2014*, "Chapter 4 Highlights," http://www.nsf.gov/statistics/seind14/index.cfm/chapter-4/c4h.htm.

153. As used here, *national laboratories* include laboratories and centers at the DOE, DOD, NOAA, NASA, NIST, USDA, and NIH.

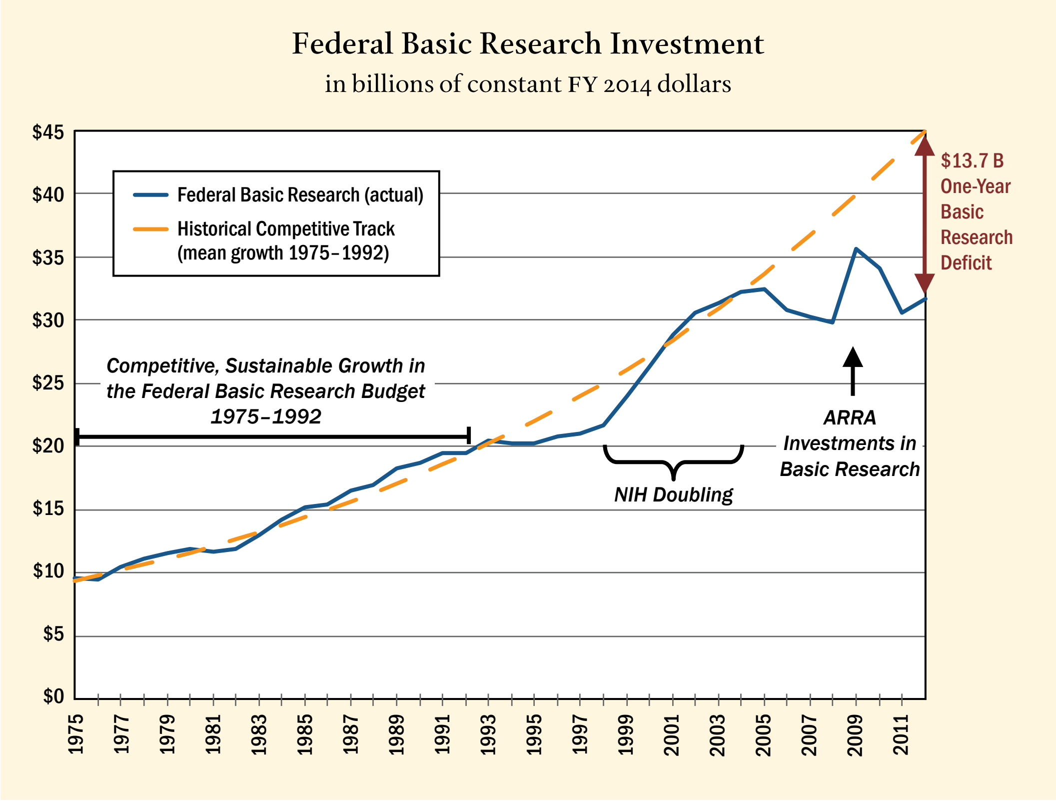

Figure 8

The Federal Investment in Basic Research, 1975 – 2011

Federal obligations in basic research (blue) experienced competitive, sustainable growth (orange) from 1975 to 1992, averaging an annual inflation-adjusted growth rate of 4.4 percent. Since then, federal funding of basic research has become increasingly unpredictable, deviating from the sustainable funding path and resulting in a $13.7 billion basic research shortfall in 2012 (red).

Note: Orange trend line is a best fit (least squares regression) of federal obligations for basic research (constant 2014 dollars) between 1975 and 1992.

Source: 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." Constant dollar conversions from 2005 to 2014 dollars are based on OMB's GDP deflators from the FY 2013 budget. 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, doi:10.1787/5kgondkjvfhf-en. Projected constant dollar values for the federal investment in basic research are based on the mean real annual growth rate from 1975 – 1992.

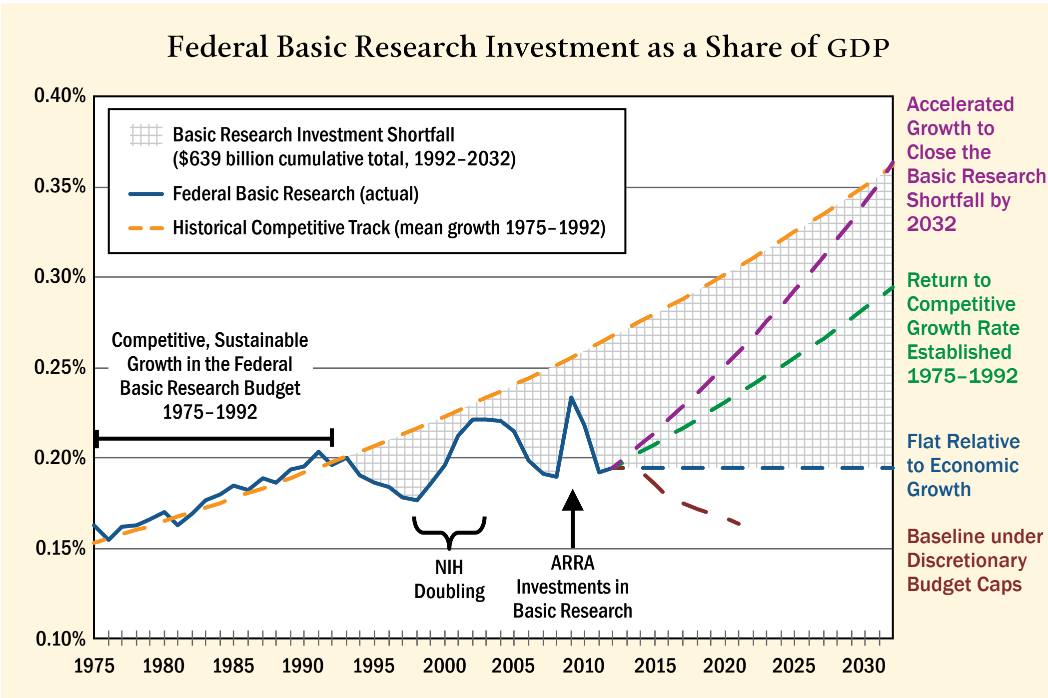

Figure 9

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.

Note: Orange trend line is a best fit (least squares regression) of federal obligations for basic research (percentage of GDP) between 1975 and 1992.

Refer to Appendix C (page 137) to view this graph in constant dollars.

Source: 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, doi:10.1787/5kgondkjvfhf-en.

Moreover, there is no long-term plan or planning process for federal research funding and no multiyear planning or capital budget, even for research infrastructure. Reliance on annual budget cycles makes strategic planning all but impossible for the research funding agencies, as well as universities, medical schools, national laboratories, and the companies collaborating with these research institutions. The effect is even more severe for federal agencies working to support large research grants, sign cooperative agreements, or establish shared experimental facilities. Corporations would likely go out of business operating in this fashion.

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 9, page 82). 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,[154] 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.

154. *America COMPETES Act*; and *America COMPETES Reauthorization Act of 2010*.

Challenges and opportunities: The committee recognizes the difficulty of increasing federal research support in a period of fiscal constraints, yet it would be difficult to overstate the urgency of this goal. As is emphasized throughout this report, investments in basic research are just that: *investments*. America's economic ascendency in the twentieth century was due in large part – perhaps even primarily – to its investments in science and engineering research.[155] In the hyper-competitive twenty-first century, the nation's relative economic power will rest to an even greater extent on American innovation – innovation that in turn depends on basic research, the majority of which is conducted in academic laboratories where future generations of scientists and engineers get their grounding. Failure to act now may put us in a position from which we cannot recover, given the fast pace of global scientific advancement.

ACTION 1.2 – We recommend that the President and Congress adopt *multiyear 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.

Challenges and opportunities: The committee recognizes that there are constitutional limits to what Congress can do in terms of committing future Congresses to the decisions of past Congresses. But by stabilizing year-to-year funding, the federal government could eliminate some large costs that result from the inability of agencies to plan ahead for large, multiyear projects such as the construction of major instrumentation and facilities. In Action 2.2 of this report, we recommend that universities and federal agencies take a hard look at their policies and practices and consider implementing "best practices" that could reduce costs and increase productivity of the nation's research enterprise.

ACTION 1.3 – We recommend that the White House Office of Management and Budget 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.

Challenges and opportunities: One of the well-established business practices that corporations have employed to good advantage is the use of capital bud-

155. Solow, "Technical Change and the Aggregate Production Function"; and Edward F. Denison, *Trends in American Economic Growth, 1929 – 1982* (Washington, D.C.: Brookings Institution, 1985).

geting to ensure that investments in equipment, plants, and R&D pay off in the long run for stockholders. In the case of the U.S. federal government, the stockholders are tax-paying Americans who rightly expect that their money is being used to the best advantage. A capital budget process would reassure the public and provide tangible benefits. In particular, it would allow for a more strategic and cost-effective approach to planning and funding the construction and operations of major instrumentation and facilities, especially those that will be used by researchers supported by multiple federal agencies. An example of the latter is DOE's light sources and neutron scattering facilities. OMB should work closely with the OSTP and the NSTC in this effort.

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.

Challenges and opportunities: Regardless of whether the federal government adopts capital budgeting as a business practice, it is important to consider each fiscal year budget in the context of a long-range plan. Such an exercise would require coordination across several federal agencies, especially regarding plans for large multiyear projects such as the construction and operation of major instrumentation and facilities whose users may be supported by multiple agencies. While individual agencies try to plan ahead, budget uncertainties work against effective strategic planning. Moreover, when the potential users of such instruments are supported by different agencies, the budget constraints or shifting priorities of one agency can negatively impact others. More transparency and better coordination of plans and budgets could alleviate much of this problem. Through its coordinating committees, the NSTC could play a larger role. A strong science caucus in the House and Senate could assist in coordinating plans across the many committees that have jurisdiction over federal research agencies and their budgets. Any such plan should be guided by periodic high-level reviews of the nation's SE&T enterprise and the federal research portfolio (see Action 2.1); the agencies' priorities in support of their respective missions; and the assessments and recommendations contained in various independent reports (authored by such organizations and bodies as the National Academies' NRC, PCAST, the NSB, and the American Academy of Arts & Sciences). The NRC decadal surveys in fields such as astronomy, particle physics, and certain other disciplines provide useful guidance to the agencies in setting their priorities and long-range budget plans. With the National Academies, the agencies should continue to explore other approaches to involving the research community in long-range planning.

Prescription 2

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

Providing sustainable federal research funding and setting long-term investment goals are vital to America's leadership in SE&T. But many current policies and practices in government, industry, and universities hinder the most effective use of the investments.

The U.S. federal science and technology policy-making apparatus, established during and immediately after World War II, served the nation well for over sixty years. But continuous changes in government (federal and state), universities (public and private), U.S. business and industry, and the rest of the world necessitate greater attention to the state of the nation's SE&T enterprise. Maintaining a leadership role will require a more strategic, long-range approach to science and technology policy, particularly prioritization of R&D investments with greater emphasis on basic research, better coordination of federal government efforts, and the reduction of unnecessary bureaucratic barriers to productivity in all sectors.

Given the rapid pace of change in SE&T in this era, American policy-makers in all sectors would benefit from access to current information and updated policy analysis and options, including those that are routinely offered by leading policy research centers around the country. Absent is a mechanism that could: 1) ensure that data, analysis, and policy recommendations are kept up to date, revised as appropriate, and made available to policy-makers in forms that are most useful to them; and 2) keep the American people informed about the state of the nation's SE&T endeavor – especially its research efforts – and the implications thereof for the American way of life.

Meaningful progress will depend on the extent to which the GUI sectors can cooperate effectively in sharing information and supporting important policy changes, particularly those described below.

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 National Science Board,[156] and with input from the federal agencies that sit on the President's National Science and Technology Council. The report, if released with the President's budget, would provide information useful for both the appropriations and authorization legislative processes.

> **Challenges and opportunities:** The federal government currently has no mechanism as a regular part of its planning and budget process to take stock of the state of U.S. SE&T in a rapidly changing high-tech global economy, to define strategic long-term goals, and to align federal policies with evolving national goals. The OSTP does focus on these issues, but its approach and impact vary with administrations, and there is no counterpart in Congress. The Quadrennial Defense Review (established in 1997) helps define long-term strategy for the DOD, and the new Quadrennial Energy Review promises to do the same for the nation's energy goals, especially the priorities of the DOE. While a quadrennial review of the nation's SE&T might be appropriate and was considered by the committee, it would be a complex, high-overhead undertaking given the large number of federal agencies involved in SE&T – application as well as R&D – and the rapid pace of technological change today.
>
> Fortunately, there is a way forward that does not involve creating new structures or layers of government: namely, a biennial report by the President, released near the same time as the publication of the *Science and Engineering Indicators*, which is externally reviewed and published by the NSF NSB every two years. The President's report could be a powerful mechanism for soliciting broader national thinking on timely SE&T matters, including implications of the trends and data presented in the *Indicators*. The NSF is mandated by statute to collect data on all aspects of SE&T,[157] and the *Indicators* are based on these data and analyses. Topics covered in the 2014 *Indicators* include: STEM education (kin-

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156. The statutory authority of the NSB is included under U.S. Code 42, Chapter 16, Paragraph 1863: "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." See http://www.law.cornell.edu/uscode/text/42/chapter-16.

157. Ibid.

dergarten to graduate school); SE&T workforce; R&D (national, international, and academic); industry, technology, and the marketplace; public attitudes and understanding; and state indicators. The White House OSTP is in an ideal position to develop for the President a "State of American SE&T" report, with input from all the NSTC agencies and coordinated with the Council itself, having received advice from PCAST.

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.

Challenges and opportunities: The federal government has an obligation to ensure that the funds it provides to universities in support of research on their campuses is used for the intended purposes; that the laboratories are safe places for students, faculty, and staff to work; and that research practices are held to high standards of performance. However, a recent report from the NSB shows that decades of accumulation of rules, regulations, and business practices by different federal agencies are placing heavy requirements on researchers and their institutions that reduce research productivity.[158] In part, these inefficiencies are due to variations among different funding agencies. But the full set of relevant regulations and practices should be examined with the objective of maximizing the effectiveness of the federal research investment.

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 Research Council report *Research Universities and the Future of America*.[159]

Challenges and opportunities: Research universities are expected to deliver a quality product – educated men and women and the discovery of new knowledge – at reasonable cost to those paying tuition and the governments and others who support university activities. But for a university to achieve excellence, it

158. National Science Board, *Reducing Investigators' Administrative Workload for Federally Funded Research* (Arlington, Va.: National Science Foundation, 2014).

159. National Research Council, *Research Universities and the Future of America*.

must compete with other universities around the world for outstanding faculty who excel in teaching and research and a talented and diverse student population that enriches the university community. This necessary competition, coupled with the uncertainties and shifting priorities of government (state and federal), undermines the making of sound business decisions by any university.

ACTION 2.2c – We recommend that universities and the National Institutes of Health gradually adopt practices to foster an appropriately sized and sustainable biomedical research workforce.[160] 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.

Challenges and opportunities: This committee agrees with the observations made in a recent paper from Bruce Alberts and his colleagues that argues there is an unsustainable disequilibrium in NIH-supported biomedical research at American universities, which is particularly severe in academic medical centers.[161] Similar observations have also been made in earlier reports, including ARISE 2[162] and the NIH Biomedical Research Workforce Working Group report.[163] As Alberts and his colleagues postulated, this disequilibrium likely developed with the expectation that the NIH budget would continue to expand over time, as might have been the case if the federal investment in basic research had kept pace with economic growth (see Action 1.1). While we recommend that investment in basic research should stay slightly ahead of national GDP, measures described in Action 2.2e would address short-term problems and make the academic biomedical research enterprise more robust in the long term. It will

160. 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.

161. Bruce Alberts, Marc W. Kirschner, Shirley Tilghman, and Harold Varmus, "Rescuing U.S. Biomedical Research from its Systemic Flaws," *Proceedings of the National Academy of Sciences* 111 (2014): 5773–5777.

162. American Academy of Arts & Sciences, *ARISE* 2.

163. National Institutes of Health, *Biomedical Research Workforce Working Group Report* (Bethesda, Md.: National Institutes of Health, 2012), http://acd.od.nih.gov/biomedical_research_wgreport.pdf.

take time to phase in these changes, but this goal is critical to the sustainability of the nation's research enterprise.

Along with the goals enumerated above, the NIH should update its Facilities and Administrative (F&A) cost formula so that its grants more fully cover the current indirect cost of research. The existing formula has not kept pace with true indirect costs for administration and infrastructure, and may have incentivized overbuilding of research facilities.[164] Redesigning the indirect cost calculation would better align research costs with funding and would allow universities (particularly medical schools) to use their limited resources to provide more salary support for faculty members who commit most of their time to biomedical research. We note that Alberts et al. also argued for long term (five-year) fiscal planning for congressional appropriations to the NIH, similar to our previous somewhat broader recommendation (see Action 1.2).

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.

Challenges and opportunities: Peer review, as it is used here, refers to the system used by the NSF, NIH, DOE's Office of Science, NASA, and other research funding agencies to evaluate unsolicited grant proposals. The program officers solicit opinions from experts in the field regarding the proposed research through mail reviews and study sections or panels. This system has been used successfully for over half a century. Critics argue, with some merit, that the reviews tend to be conservative, discouraging high-risk projects, and that they favor experienced researchers over early-career researchers. Research funding agencies continue to revise their procedures to address these and other concerns in an effort to improve the review process. However, no better system has been devised, particularly for basic research, where the likely outcome cannot be predicted.

164. Association of American Universities, "Strengthening the Government-University Partnership: A Discussion Paper on University Indirect Cost Reimbursements," September 2010, 1 – 15.

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

Challenges and opportunities: The peer-review system, which has long been accepted as the most effective way to make grant award decisions, requires that a researcher accept two roles: writing proposals for his or her research and voluntarily reviewing the proposals of others. Unless the nation's researchers do both these things well, the effectiveness of the system is reduced; but there is no viable substitute at present.

In the past decade, at least two influences have combined to challenge the system for granting research funding. First, federal research funding has been reduced in real terms, as discussed in this report. Second, as a result of substantial federal investments in research and STEM education made in earlier decades, the number of researchers seeking support has increased. Between 1998 and 2011, the NIH saw a 40 percent increase in the number of applicants for research project grants.[165] As a result, researchers are writing and reviewing more proposals than in the past, grant award success rates have been dropping (Figure 10, page 92), and it is taking longer for new investigators to win their first grant (Figure 11, page 93). This committee agrees with the recent NSB report that argues that these and other administrative burdens on investigators should be reduced so that investigators can focus on the conduct of science.[166] In addition to increasing support for the grant process, agencies should explore new approaches. In some agencies, the added volume of proposals has imposed undue burdens on the program officers who manage the grant process. In the same vein that professional journals use part-time editors based in university campuses and national laboratories, non-resident program officers may be a viable option.

165. Sally Rockey, "More Applications; Many More Applicants," NIH Extramural Nexus: Rock Talk Blog, August 9, 2012, http://nexus.od.nih.gov/all/2012/08/09/more-applications-many-more-applicants/.

166. National Science Board, *Reducing Investigators' Administrative Workload for Federally Funded Research*.

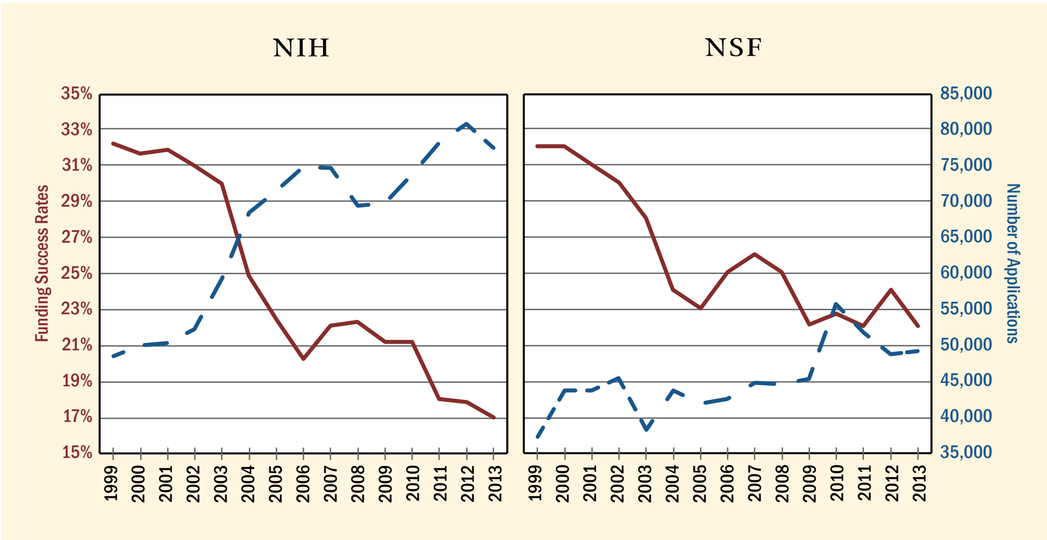

Figure 10

Declining Funding Success Rates and Increasing Demand

As the number of grant applications to the NIH, NSF, and other federal funding agencies have increased (blue), success rates have plummeted (red), reaching an all-time low at the NIH in 2013.

Source : NIH statistics are from the Office of Extramural Research (OER) ; Office of Planning, Analysis and Communications (OPAC) ; and Division of Statistical Analysis & Reporting (DSAR), Table #218, "Success Rates of NIH R01 Equivalent and Research Project Grants Applications, Fiscal Years 1970 – 2013." Data drawn from National Institutes of Health, "Research Portfolio Online Reporting Tools (RePORT)," frozen FY 2013 success rate file, http ://www.report.nih.gov/success_rates/index.aspx (accessed December 13, 2013). NSF statistics are from National Science Foundation, NSF Budget Requests to Congress and Annual Appropriations, FY 2001 – FY 2015, http ://www.nsf.gov/about/budget/.

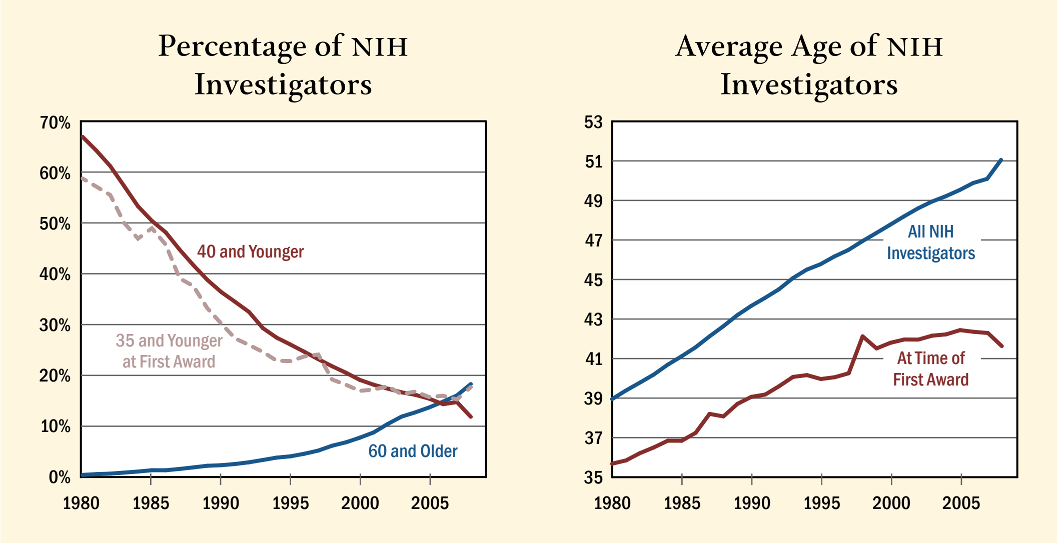

Figure 11

Fewer Opportunities for Young Researchers

Left panel: The percentage of academic researchers under the age of forty who are funded by the NIH (solid red line) has been in steady decline over the past few decades, while those researchers over the age of sixty (blue line) has steadily increased. It has also grown more difficult for new investigators to win their first grant: the percentage of investigators under thirty-five years old at the time of their first award (dotted red line) was 15 percent in 2007, although new NIH policies resulted in an upward tick to 18 percent in 2008. Right panel: Researchers have been delayed in receiving their first grant (red line) – a critical first step in establishing a new lab – by roughly six years since 1980. The average age at first award in 2008 was nearly forty-two years, the same age at which scientists like Albert Einstein, Marshall Nirenberg, and Thomas R. Cech won their Nobel Prizes.

Source: National Institutes of Health Office of Extramural Research, "Age Data on NIH Principal Investigators, 1970–2006," http://report.nih.gov/FileLink.aspx?rid=799. Includes age of stock, age of new investigators, age gap in funding, and age at reentry.

Summary of Recommendations from "Rescuing U.S. Biomedical Research from its Systemic Flaws"

Drawn from Bruce Alberts, Marc W. Kirschner, Shirley Tilghman, and Harold Varmus, "Rescuing U.S. Biomedical Research from its Systemic Flaws," *Proceedings of the National Academy of Sciences* 111 (2014): 5773–5777.

1. **Plan for predictable and stable funding of science** by adding a five-year projected fiscal plan to the current budgetary process.
2. **Bring the biomedical enterprise into sustainable equilibrium**
    a. Educate graduate students by transitioning to a system in which they are supported with training grants and fellowships, not research grants.
    b. Broaden the career paths for young scientists by providing opportunities to explore a variety of career paths and expanding master of science degree programs.
    c. Train postdoctoral fellows by gradually increasing compensation for federally funded postdoctoral fellows and limiting the total number of years of federal research grant support for postdoctoral fellows.
    d. Employ staff scientists by increasing the ratio of permanent staff positions to trainee positions in laboratories and core facilities.
3. **Foster grant-making that improves scientific productivity**
    a. Improve the goals and mechanisms for scientific grants through wider use of grant mechanisms that provide more stable support and focus on the quality of investigators' science; by developing funding mechanisms that encourage the growth of new fields; by creating new awards that emphasize risk-taking; and by carefully examining grant portfolios before increasing direct research support for a laboratory beyond $1 million each year.
    b. Improve evaluation criteria by refocusing performance evaluation tools on identifying the strongest candidates for support and adjusting review guidelines to promote the funding of proposals that reveal ingenuity and promise findings with broad implications.
    c. Strengthen grant review panels by taking advantage of the full range of talent in the scientific community, broadening the range of scientific problems judged by each group, and including a diversity of fields represented on each panel.
    d. Evaluate programs, policies, and their implementation and make the findings publicly accessible.
4. **Address policies that undermine sustainability** by gradually revising policies and practices regarding indirect cost recovery over the next decade.

ACTION 2.3 – We recommend that the National Academies, the American Association for the Advancement of Science, and the American Academy of Arts & 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 policy-makers 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 (see sidebar, page 97).

Challenges and opportunities: The United States is fortunate to have a large number of nongovernmental organizations (NGOs) that focus on various aspects of SE&T, and in some cases, particular research disciplines. Many of these organizations conduct studies and offer advice on policy reforms that they argue would improve the efficiency and effectiveness of federal programs and funding. But there is no coordinated mechanism to keep these policy ideas updated and accessible to policy-makers. Most of these NGOs do have outreach activities aimed at informing the public (including business and community leaders) about new discoveries and applications that can be traced to research funded by the federal government. They all add value to the policy debates and the public's interest in and awareness of the continuing impact of science and technology on every person's life. But by and large they do not work together and thus they miss an opportunity to have a larger collective voice. By starting a conversation among these organizations we hope that such a collective effort could emerge.

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, 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.

Challenges and opportunities: The committee supports the recommendation made by many other organizations that Congress fully fund the Office of Technology Assessment to restore a critical source of S&T policy analysis. However, the committee also recognizes that repeated attempts to restore funding for the OTA have not been successful and that alternative approaches should therefore be considered. In recent years, the GAO has assumed some responsibilities previously carried out by the OTA, but its resources in the area of technology assessment are still a small fraction of those once provided to the OTA. The independent, expert scientific and technological advice to Congress once provided by the OTA and now provided by the GAO will be even more important in the coming decades given the accelerating pace of scientific discovery and technological innovation and the number of global issues that involve major scientific and technological considerations.

Sustaining a Focus on Long-Term Science, Engineering, and Technology Policy

The mission of the task force recommended under Action 2.3 would be to provide independent advice to universities, industry associations, private foundations, and the federal (and perhaps state) government on how these sectors, individually and working in partnership, could help ensure that the nation retains a leadership role in science, engineering, and technology—R&D, education, and innovation—in future decades.

The task force would be the nation's primary source for updated information about the status of findings and recommendations that have been put forward by a number of respected organizations, including the National Academies' NRC, the American Academy of Arts & Sciences, the NSB, and PCAST. Specifically, it would 1) track the implementation of past policy recommendations; and 2) work with other nongovernmental policy organizations, science and engineering societies, foundations, and business organizations to discuss how to maintain visibility for these recommendations over time.

Ideally, the task force would have a minimal but dedicated professional staff and would receive operating support from a consortium of federal agencies, university and industry organizations, foundations, and think tanks.

Its recommendations could be advanced by a council that includes current or former senior representatives from each of the above stakeholders. Following the model exemplified by Vannevar Bush, Charles M. Vest, and other leading advocates for sound S&T policy, each member of the council should agree to dedicate at least twelve days per year to outreach among state and federal policy-makers. They should also commit to "passing the torch" by identifying and cultivating the next generation of S&T advocates from universities, corporations, foundations, and nongovernmental organizations.

Prescription 3

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

The strong government-university research partnership established during World War II has been the key to America's progress in science, engineering, technology, medicine, and innovation for more than half a century. Erosion in this partnership and the prolonged weakness of much of the industry partnership has contributed to placing the health of the American SE&T enterprise at serious risk.

Following World War II, large corporations also established their own central R&D laboratories that focused on the companies' needs, but also supported a considerable amount of basic research, some of which led to Nobel Prizes. Those labs have largely atrophied or disappeared, and industry increasingly depends on research conducted in universities, medical schools, and national laboratories.

Today, the United States needs a new kind of research partnership: a robust national effort involving government (federal and state), universities (public and private), and industry, as well as philanthropy and private foundations, in which each sector accepts and fulfills its responsibilities in support of the nation's leadership in science and engineering research, especially basic research. Other countries recognize this need and are taking active steps to put such national GUI research partnerships in place. Yet in the United States, the accumulation of decades of policies and practices in each sector, as well as shifting priorities of the states and unpredictable federal research funding levels, are allowing our nation to steadily fall behind. The innovation deficit looms large.

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.

Challenges and opportunities: The recommendations in this report will not become institutionalized without strong national leadership in all sectors. To capitalize fully on the nascent efforts already underway across the country, the Summit should highlight examples of successful research collaborations, including those that require little to no federal support, such as university-industry consortia on energy research and external innovation programs in the pharmaceutical sector. The Summit should then identify ways to facilitate future collaborations between universities and corporations, including with the assistance of private foundations and individual philanthropists.[167]

The Summit should also assess progress on the implementation of reforms recommended by previous studies, including recent reports by PCAST, the National Academies, the American Academy of Arts & Sciences, and others that address GUI sectors (see Focus Section B, page 46 for selected examples) and agree on a roadmap and benchmarks for making further progress. By focusing the Summit on an evaluation of progress and future steps that should be taken, the event would provide critical momentum to changes, many of which are already underway in some sectors (see sidebar, page 100).

As a follow-up to the "Summit on the Future of America's Research Enterprise," we recommend that the President request from the OSTP or PCAST a set of specific reforms by the federal government that would strengthen the GUI research partnership. In addition to actions that the President might wish to take, these recommendations should provide guidance to the next administration and Congress.

If the Summit has an action agenda with significant buy-in from all sectors, the committee believes it could be the key to launching a national conversation about America's future in SE&T.

167. For example, see the Science Philanthropy Alliance (http://sciencephilanthropyalliance.org/), a consortium of six foundations formed with the goal of doubling support for basic research from American philanthropists and foundations within ten years.

An Agenda for the "Summit on the Future of America's Research Enterprise"

By convening leaders of the nation's research universities, state and federal governments, corporations, and private philanthropic organizations, as well as top research officials from agencies, companies, and national laboratories, the Summit could provide an opportunity to reassert America's commitment to leadership in science, engineering, and technology by defining a vision for the country's future in a rapidly evolving world. It would also provide a venue for a system-wide assessment of progress on overcoming barriers to the discovery of new scientific knowledge and technologies, the translation of these discoveries to business and industry, and the preparation of a future STEM workforce that is commensurate with maintaining America's position of leadership in the world. To achieve this objective, the Summit should:

- **Highlight the success of innovative government (federal and state)-university-industry partnership arrangements**, including progressive approaches to managing intellectual property developed through federally funded research at universities and national laboratories.
- **Identify and assess progress in addressing the remaining barriers**, both practical and regulatory, to adopting new models for technology creation and translation to applications by business and industry.
- **Announce new policies and initiatives that each GUI sector could take to increase intellectual exchange**, including shared core facilities, short- and long-term researcher exchanges and part-time positions within the GUI domain, research collaborations involving teams of researchers from different sectors, and innovative ways to advance a national GUI research partnership.
- **Celebrate the important role of philanthropy in supporting research and highlight planned efforts to increase private investments in science and engineering research.**
- **Seek common accord on a national vision for American science, engineering, and technology, including the dual goal of:**
  - Establishing a more strategic, long-term approach to science and technology policy-making at the federal level; and
  - Sustaining a total national R&D investment (public and private) of at least 3.3 percent of GDP, with special emphasis placed on federal funding of basic research.
- **Identify how each sector could most effectively support and benefit from these goals.**

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.

Challenges and opportunities: The Bayh-Dole Act (Patent and Trademark Law Amendment Act) of 1980 allows universities, small businesses, and nonprofit organizations to pursue ownership of an invention arising from federally funded research, subject to a number of conditions. This landmark legislation has been highly effective in getting IP into the hands of companies, including start-ups, that can develop products from the technology and move them to market, and has enabled a small number of universities to derive substantial income from licensing. However, the majority of universities have found that the cost of maintaining a technology transfer office, filing for patents, and negotiating IP licensing exceeds the income generated from licensing. Licensing negotiations with companies can also pose a high barrier to collaboration, often delaying or preventing the transfer of technologies to a company and, potentially, to market. These realities have spurred many universities to reconsider the value of IP ownership relative to strengthening partnerships and conducting more research. Some universities are experimenting with new policies to enhance the transfer of IP to the market and are implementing novel technology transfer practices in line with this policy (see Focus Section C, page 67). More universities should attempt such experiments, the outcomes of which should be evaluated to derive best practices, while staying mindful of legitimate concerns that accompany UI partnerships, including potential conflicts of interest, restrictions on public access to research results, and the potential for resulting constraints on future research conducted in university and government laboratories.

Ph.D. graduates from U.S. research universities possess the depth of knowledge, analytical and technical skill set, and critical thinking skills that are essential to a successful career in research. Those attributes are also important for myriad other professions, including business and industry, especially when combined with other professional skills. Today, most Ph.D. programs are not focused on providing that complementary skill set. And with less than 20 percent of Ph.D. graduates in SE&T disciplines securing stable academic positions (including tenure and tenure-track positions) within three to four years of receiving their doctorate,[168] many graduates are not sufficiently prepared to launch successful careers outside academia. Professional science master's (PSM) degree programs offer an additional year or two of focused study for students who wish to pursue non-research careers in business, engineering, K – 12 education, public health, and other fields. Graduates tend to do well even in tight hiring markets.[169]

Faculty leadership and cooperation will be the key to advancing these reforms; and the professional science and engineering societies will continue to play an important role by keeping their members informed about best practices through conferences, publications, and websites. The committee notes that these efforts can be enhanced through implementation of the recommendation of the NRC Committee on Research Universities that "business, government agencies, and nonprofits . . . should more deeply engage programs in research universities to provide internships, student projects, advice on curriculum design, and real-time information on employment opportunities."[170]

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

168. Y.-G. Lee and M. R. Connolly, "Career Pathways of STEM Doctorate Recipients" (2014). Unpublished raw data from the Longitudinal Study of Future STEM Scholars (LSFSS). These data are drawn from a 2013 survey representing nearly seven hundred doctoral students in STEM fields at three participating research universities who received their doctorate in either 2009 or 2010.

169. Jeffrey R. Allum, *Outcomes for PSM Alumni: 2012/13* (Washington, D.C.: Council of Graduate Schools, 2013).

170. National Research Council, *Research Universities and the Future of America*, 17.

- 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.

  Challenges and opportunities: The Bayh-Dole Act has been highly effective in advancing IP generated from federally funded research to market. Numerous studies, including a report by the NRC, uphold this legislation, finding that the system put in place by the Bayh-Dole Act is "unquestionably more effective than its predecessor."[171] Over several decades, however, it has become clear that modification of certain policies and regulations could further propel the flow of IP to market by promoting the creation of start-up companies and by enhancing cooperation between universities, government, and industry. As described in Action 3.2, experimentation with IP licensing policies and practices should be encouraged, while staying mindful of conflicts of interest and other concerns.

  Further, certain provisions in the tax code pose a barrier to UI research collaborations by preventing the university from entering into licensing arrangements with the industry sponsor *before* the resulting technology is ready for the market. While the original intent of these provisions was to prevent abuses of tax-exempt bonds, they have also served as a roadblock for negotiations on future collaborative efforts. In order to engage more freely in research with for-profit entities, some universities do not finance new facilities with tax-exempt bonds but instead choose to issue taxable bonds or put some of their own equity into the capital budget to finance those facilities, which is common in biomedical research. However, many universities do not have the capital to make such investments, thereby limiting their ability to engage in research partnerships with industry.[172]

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171. National Research Council, *Managing University Intellectual Property in the Public Interest*.

172. David M. Kettner and William J. Decker, "Fundamentals of Technology Transfer and Intellectual Property Licensing," National Association of College and University Attorneys, November 2004, http://www.higheredcompliance.org/resources/intellectual-property-technology-transfer.html.

FOCUS SECTION E

Unlocking the Full Potential of American Innovation through Enhanced Technology Transfer

The 1980 Bayh-Dole Act unlocked the transfer of technology from universities to industry by fundamentally shifting the incentives structure driving the commercialization of federally funded innovations. The act has brought substantial benefits to the nation through a strengthened GUI partnership, increased economic growth, and better quality of life for the American people. And while universities remain the primary performer of basic research, other entities (private corporations, DARPA, DOE Hubs, and so on) are also heavily engaged in research.

Nevertheless, the effectiveness of university technology transfer could be further enhanced by establishing new incentives to promote flexibility in UI partnerships, and by lowering barriers to marketing innovations that have potential for advancing the public good. As observed by the National Academies NRC report *Research Universities and the Future of America*:

> The relationship between business and higher education should evolve into more of a peer-to-peer nature, stressing collaboration in areas of joint interest rather than the traditional customer-supplier relationship in which business procures graduates and intellectual property from universities.[173]

Recommended Actions 3.2 and 3.3 represent important steps toward reducing regulatory and cultural barriers to deeper UI collaboration. This committee finds, however, that more data is urgently needed to guide universities, national laboratories, and federal programs in determining the proper approach to technology transfer for their particular institutions. There are also financing barriers to the commercialization of federally funded innovations, yet insufficient information is available to determine whether new financing mechanisms are necessary to maximize the uptake of IP by the private sector. Some financial barriers may be sector-specific, such as the funding gap that contributes to the "valley of death" in areas like clean energy and pharmaceuticals.

173. National Research Council, *Research Universities and the Future of America*, 92.

Clarity on these issues will require comprehensive sector-by-sector studies of the following questions by an authoritative body or bodies, such as PCAST, the National Academies, and/or the National Bureau of Economic Research:

1. What are the overall economic propositions for technology transfer from universities through their ownership of IP, versus the value universities would derive through partnerships with the private sector wherein much of the ownership of the IP by the university is foregone? This study should include the full costs of the administrative and legal complexities associated with technology patenting, licensing procedures, lost opportunities for partnerships with the private sector, and other costs associated with university IP ownership.

2. To what extent is federally funded IP not being exploited commercially? This study should ascertain how financial or access barriers impact commercialization, despite the important progress made by programs such as ARPA-E and Small Business Innovation Research (SBIR). The study group should then seek to identify a mechanism to advance the uptake of this IP by private companies, including venture capital firms. For example, the study could analyze the merits of establishing a federally chartered national or regional SE&T research entity that has the ability to invest and grow its initial budget and retain exclusive IP rights to the research results, while partnering with TTOs at universities and the national laboratories. If warranted, the study should produce a roadmap for establishing a pilot program in one or two technological areas where there is a clear need to bridge the funding gap that exists between basic research and commercialization.

ACTION 3.4 – We recommend that the federal agencies that operate or provide major funding for national laboratories[174] 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.

> **Challenges and opportunities:** Most of the nation's federally supported laboratories were established during World War II or early in the Cold War; and while the federal agencies that fund them have redirected their missions and operations to meet changing needs, there has not been a government-wide review to determine how these institutions can best serve the national interests of both today and the future. In May 2014, Secretary of Energy Ernest Moniz announced the DOE's Commission to Review the Effectiveness of the National Energy Laboratories, whose activities will include reviewing the *missions* of DOE's national laboratories. This committee applauds this effort and urges that similar efforts be applied to all of the national laboratories. The accumulation of decades of rules, regulations, reviews, assessments, and other practices – perhaps appropriate in earlier years – constitute significant burdens to the laboratories' effective operations. In particular, the effectiveness of collaborations with universities and corporations has been uneven, in part because of the many federal policies and practices that discourage cooperation. Reducing such burdens could substantially increase the productivity of the laboratories and should be viewed as a high priority, especially during times when federal funding is severely constrained, as is the case today.

174. As used here, *national laboratories* include intramural laboratories and centers at the DOE, DOD, NOAA, NIH, NIST, USDA, and NASA.

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

> **Challenges and opportunities:** As universities move away from IP policies that emphasize licensing revenues to more flexible approaches that are intended to build stronger two-way relationships with industry, companies can encourage these reforms by increasing their investments in university research. With the recent downturns in state and federal government support, it is increasingly necessary for university researchers to attract funding from other sources. And while managing multiple grants and contracts from different sponsors is complicated (and adds overhead), the result can be a richer, more innovative research environment that benefits all sponsors, as well as the students who do much of the work and seek employment. The opportunity for strengthening the UI partnership has never been greater.

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, 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.

> **Challenges and opportunities:** The arguments for making the R&E Tax Credit permanent are compelling. Companies argue that they cannot afford to make long-term R&D commitments in the United States while lacking assurance that the tax credit will be available in the future. In particular, this uncertainty impedes the formation of stronger research partnerships with universities, especially in basic research, which is most appropriate for an academic institution. This flaw in federal policy significantly reduces the potential benefits that federally supported academic research can provide to American taxpayers. This fact should override any political arguments for the status quo.

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,[175] 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.

> **Challenges and opportunities:** Graduate students from around the world seek an elite education at American research universities, not only for the quality of training they receive but to advance their careers.[176] For these reasons and others, most of these talented international students and researchers would stay in the United States if given the opportunity. However, international competition for talented scientists and engineers has grown fierce, and American corporations, mirroring corporations around the world, have become increasingly multinational. If we fail to both *attract* and *retain* the best and brightest scientists and engineers, we risk not only steering American entrepreneurs to site their R&D overseas in pursuit of highly skilled workers, but also further exacerbating the current shortage of educated workers to fuel American R&D and high-tech manufacturing sectors.

175. See President's Council of Advisors on Science and Technology, *Transformation and Opportunity*; Institute of Medicine et al., *Rising Above the Gathering Storm*; and National Research Council, *Research Universities and the Future of America*.

176. Richard Van Noorden, "Global Mobility: Science on the Move," *Nature* 490 (2012): 326–329.

Conclusion

The American Dream is a national ethos whose foundation is rooted in opportunity: the opportunity for a quality job, a quality life, and a quality education; the opportunity for our children to achieve more than we could and enjoy a better life than we experienced. It imbues the nation with a spirit of hard work and determination. Without opportunity, the Dream fades, and with it goes a key part of our identity as a nation.

These core opportunities are also interconnected: if one fails, the others will follow. Quality of life and well-being rely to a large extent on having a quality job, and both are bound to the health of the nation's economy. Studies have shown that the predominant driver of economic growth over the past half-century has been scientific and technological advancement, the foundation of which is basic, discovery-based research. The federal government is the primary funder of basic research in this country, and is the only reliable source of support for basic research at this scale.

Basic research replenishes a pool of knowledge and ideas that grows new products and processes that benefit the American people and strengthen the economy. This process of innovation is not linear, but rather forms a highly interconnected web that engages not only the federal government and universities, but also business, industry, state governments, and philanthropy. If the United States is to take full advantage of this unparalleled period of rapid scientific and technological advancement, then this complex system of research and invention must thrive.

The recommendations presented in this report, if acted upon, will move the nation from gliding to propelling research, from an unguided to a strategic enterprise, and from a short-term to a long-term focus by establishing a more robust twenty-first-century research partnership across all sectors and by securing American competitiveness through sustainable federal funding for basic research. It is our hope that Americans from all backgrounds and professions will work together to achieve these goals and ensure that our nation and its citizens continue to thrive for generations to come.

Appendices

Appendix A: Committee Biographies

Norman R. Augustine (Cochair) is retired Chairman and CEO of Lockheed Martin Corporation, who also served as a lecturer with the rank of Professor at Princeton University. He served as a member of the President's Council of Advisors on Science and Technology and of the U.S. Department of Homeland Security's Advisory Council, as Under Secretary of the U.S. Army, and as Chair of the Review of United States Human Space Flight Plans Committee. He also served as Chair of the National Academies committee that produced the report *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*. He is a member of the American Philosophical Society and the National Academy of Sciences, and is a former Chairman of the National Academy of Engineering. He served as Chairman and Principal Officer of the American Red Cross for nine years, Chairman of the Aerospace Industries Association, and Chairman of the Defense Science Board. He is a former President of the American Institute of Aeronautics and Astronautics and the Boy Scouts of America. He has also served as a member of the Board of Directors of ConocoPhillips, Black & Decker, Proctor & Gamble, and Lockheed Martin. He chairs the NIH Scientific Management Review Board, and is a Trustee Emeritus of Johns Hopkins University and a former member of the Board of Trustees of Colonial Williamsburg, Princeton University, and MIT. He was also a member of the Hart-Rudman Commission on National Security and the Council on Foreign Affairs. He serves on the University System of Maryland Board of Regents and has authored or coauthored several books, including *Augustine's Laws* and *Shakespeare in Charge*. He was elected a Fellow of the American Academy of Arts & Sciences in 1992.

Neal Lane (Cochair) is Malcolm Gillis University Professor and Professor of Physics and Astronomy at Rice University. He also holds an appointment as Senior Fellow for Science and Technology Policy at the James A. Baker III Institute for Public Policy. He served in the federal government as Assistant to the President for Science and Technology and Director of the White House Office of Science and Technology Policy from 1998 to 2001, and as Director of the National Science Foundation and member (*ex officio*) of the National Science Board from 1993 to 1998. Before his post with the NSF, he was Provost and Professor of Physics at Rice, a position he had held since 1986. His areas of expertise include theoretical atomic and molecular physics and science and technology policy. He was elected a Fellow of the American Academy of Arts & Sciences in 1994 and is Chair of the Academy's initiative on Science, Engineering & Technology.

Nancy C. Andrews is Dean of the Duke University School of Medicine and Vice Chancellor for Academic Affairs. She is also Professor in the Department of Pediatrics and the Department of Pharmacology and Cancer Biology. Prior to moving to Duke in 2007, she served as the George Richards Minot Professor of Pediatrics at Harvard University, Senior Associate in Medicine at the Children's Hospital Boston, and a Distinguished Physician of the Dana-Farber Cancer Institute. She was the Director of the Harvard-MIT M.D.-Ph.D. program from 1999 to 2003, and Dean for Basic Sciences and Graduate Studies at Harvard Medical School from 2003 to 2007. She maintains an active NIH-funded research laboratory studying mouse models of human diseases. A Howard Hughes Medical Institute Investigator from 1993 to 2006, she is also the past President of the American Society of Clinical Investigation, a member and Governing Council Member of the Institute of Medicine of the National Academies, and Vice Chair of the Board of Directors of the Burroughs Wellcome Fund. She was elected a Fellow of the American Academy of Arts & Sciences in 2007 and serves as a member of the Academy's Board of Directors.

John E. Bryson has throughout his career focused on clean forms of energy, energy efficiency, and how public and private business leaders can help in developing new forms of energy. He is currently concentrating on solar power, the possibilities of which are now being demonstrated at the California Institute of Technology by Professor Nate Lewis and his research group. Bryson's team seeks to apply Lewis's work in India, China, and the United States to move toward providing low-cost, positive, and environmentally sustainable sources of energy. He is a Trustee of Caltech, a member of the Deutsche Bank Americas Advisory Board, and a member of the Board of Directors of the W. M. Keck Foundation. He served as Secretary of Commerce under President Obama in his first term. Prior to his government service, Bryson served as Chairman and Chief Executive Officer of Edison International (the parent company of Southern California Edison) for more than eighteen years. He formerly served as a member of the Board of Directors of the Council on Foreign Relations, the Boeing Company, the Walt Disney Company, and the Public Policy Institute of California; a member of the Board of Trustees of Stanford University; and a Senior Advisor to Kohlberg Kravis Roberts & Company. He served as a member of the U.N. Secretary-General's Advisory Group on Energy and Climate Change. Together with former U.S. Secretary of State Warren Christopher, he served as Cochair of the Pacific Council on International Policy. Earlier, Bryson was President of the California Public Utilities Commission and Chairman of the California State Water Resources Board, and for two years he presented classes on water law at Stanford Law School. He was a cofounder of the Natural Resources Defense Council. He was elected a Fellow of the American Academy of Arts & Sciences in 2011.

Thomas R. Cech is Distinguished Professor at the University of Colorado Boulder. He also serves as Director of the University of Colorado BioFrontiers Institute. He is a former President of the Howard Hughes Medical Institute, where he remains an Investigator. He was awarded the Nobel Prize in Chemistry in 1989 for the discovery that RNA could be a biocatalyst. His research group now studies the enzyme telomerase – the upregulation of which contributes to multiple cancers – and long noncoding RNAs involved in the regulation of gene expression in humans. He was elected a Fellow of the American Academy of Arts & Sciences in 1988.

Steven Chu is the William R. Kenan, Jr., Professor of Physics and Molecular & Cellular Physiology at Stanford University. His research spans atomic and polymer physics, biophysics, biology, biomedicine, and batteries. He shared the 1997 Nobel Prize in Physics for the laser cooling and trapping of atoms. From January 2009 until April 2013, he was the 12th U.S. Secretary of Energy and the first scientist to hold a cabinet position since Ben Franklin. During his tenure, he began ARPA-E, the Energy Innovation Hubs, and the Clean Energy Ministerial meetings; and was tasked by President Obama to assist BP in stopping the *Deepwater Horizon* oil leak. Prior to his cabinet post, he was Director of the Lawrence Berkeley National Laboratory, Professor of Physics and Molecular and Cell Biology at the University of California, Berkeley, the Theodore and Francis Geballe Professor of Physics and Applied Physics at Stanford University, and Head of the Quantum Electronics Research Department at AT&T Bell Laboratories. He is a member of the National Academy of Sciences, the American Philosophical Society, and the Academia Sinica; and is a Foreign Member of the Royal Society, the Royal Academy of Engineering, the Chinese Academy of Sciences, and the Korean Academy of Sciences and Technology. He has been awarded twenty-four honorary degrees, has published more than two hundred and fifty scientific papers, and holds ten patents. He was elected a Fellow of the American Academy of Arts & Sciences in 1992.

Jared Cohon is President Emeritus, University Professor of Civil and Environmental Engineering and of Engineering and Public Policy, and Director of the Wilton E. Scott Institute for Energy Innovation at Carnegie Mellon University. He served as President of Carnegie Mellon for sixteen years from 1997 to 2013. Previously, he was Dean of the School of Forestry and Environmental Studies at Yale University from 1992 to 1997. He started his teaching and research career in 1973 at Johns Hopkins University, where he was a faculty member in the Department of Geography and Environmental Engineering for nineteen years. He also served as Assistant and Associate Dean of Engineering and Vice Provost for Research at Johns Hopkins. In addition to his academic experience, he served in 1977 and 1978 as Legislative Assistant for Energy and the Environment to the late Honorable Daniel Patrick Moynihan, U.S. senator from New York. President Bill Clinton appointed Cohon to the Nuclear Waste Technical Review Board in 1995 and appointed him as Chairman in 1997. His term on the board ended in 2002. President George W. Bush appointed Cohon in 2002 to the Homeland Security Advisory Council, and President Barack Obama reappointed him in 2009 (his term on the council ended in 2013). He is a Distinguished Member of the American Society of Civil Engineers and a member of the National Academy of Engineering. He has received honorary degrees from the Korean Advanced Institute for Science and Technology, the University of Pittsburgh, and Carnegie Mellon University. He was elected a Fellow of the American Academy of Arts & Sciences in 2012.

James J. Duderstadt is President Emeritus and University Professor of Science and Engineering at the University of Michigan. His teaching and research interests span a wide range of subjects in science, mathematics, and engineering (including nuclear fission reactors, thermonuclear fusion, high-powered lasers, computer simulation, and information technology), as well as policy development in areas such as energy, education, and science. He currently serves on several major national boards and study commissions in areas such as federal science policy, higher education, information technology, energy sciences, and national security. He serves as Chair of the Policy and Global Affairs Division of the National Research Council, Codirector of the Glion Colloquium (Switzerland), Senior Scholar of the Brookings Institution, and a member of the Board of Directors of the DOE CASL (Consortium for Advanced Simulation of Light Water Reactors) Nuclear Energy Innovation Hub. He was elected a Fellow of the American Academy of Arts & Sciences in 1993.

Mark C. Fishman is President of the Novartis Institutes for BioMedical Research (NIBR) and is a member of the Executive Committee of Novartis. Before joining Novartis in 2002, he was Chief of Cardiology and Director of the Cardiovascular Research Center at Massachusetts General Hospital and Professor of Medicine at Harvard Medical School. He completed his internal medicine residency, chief residency, and cardiology training at Massachusetts General Hospital. He has been honored with many awards and distinguished lectureships and serves on the Council of the Institute of Medicine of the National Academies in the United States. He was elected a Fellow of the American Academy of Arts & Sciences in 2002.

Sylvester James Gates, Jr., is the John S. Toll Professor of Physics and Regents Professor at the University of Maryland. He also serves on the President's Council of Advisors on Science and Technology, the Maryland State Board of Education, and the National Commission on Forensic Science, and is Director of the Center for String & Particle Theory. His research interests include string theory, supersymmetry, and supergravity, focusing on mathematical graphs (adinkras) as representations of supersymmetry algebras. He has held appointments at MIT, Harvard University, the California Institute of Technology, and Howard University. Additional past service includes advisory roles to the National Science Foundation, the U.S. Department of Energy, the U.S. Department of Defense, the Educational Testing Service, and Time-Life Books. He is also a past President and current Fellow of the National Society of Black Physicists. He is a member of the National Academy of Sciences, the American Philosophical Society, and the American Association for the Advancement of Science. He was elected a Fellow of the American Academy of Arts & Sciences in 2011.

Bart Gordon is former Representative for the state of Tennessee in the United States House of Representatives and current Partner at K&L Gates. He served as congressman for twenty-six years from 1985 to 2011 and as Chairman of the House Committee on Science and Technology from 2007 to 2011. He was also a Senior Member of the House Committee on Energy and Commerce, and served on the House Committee on Financial Services and the House Committee on Rules, Transatlantic Parliamentary Dialogue, and NATO Parliamentary Assembly.

M.R.C. Greenwood is President Emerita of the University of Hawaii. She is also Chancellor Emerita of the University of California, Santa Cruz, and Distinguished Professor Emerita of Nutrition and Internal Medicine at the University of California, Davis. She served as Associate Director for Science in the White House Office of Science and Technology Policy during the Clinton administration. She was also President of the American Association for the Advancement of Science in 1999. In addition, she has served as Chair of the Policy and Global Affairs division of the Nuclear Regulatory Commission, as President of the North American Association for the Study of Obesity (now the Obesity Society), and as President of the American Society of Clinical Nutrition. She currently consults on higher education, science policy and nutrition, and women's health issues. She is a member of the Institute of Medicine of the National Academies. She was elected a Fellow of the American Academy of Arts & Sciences in 2005.

John L. Hennessy is President of Stanford University, where he also holds the Bing Presidential Professorship. He began his scientific career at Stanford in 1977. In 1981, he gathered a team of researchers to build a computer architecture known as RISC (Reduced Instruction Set Computer). In 1984, he cofounded MIPS Computer Systems, now MIPS Technologies, which designs microprocessors. In recent years, his research has focused on the architecture of high-performance computers. From 1983 to 1993, he was Director of the Computer Systems Laboratory, a research and teaching center operated by the Departments of Electrical Engineering and Computer Science. He served as Chair of Computer Science from 1994 to 1996, when he was named Dean of the School of Engineering. He was named Provost in 1999. He is the recipient of many awards, including the IEEE John von Neumann Medal, the ASEE Benjamin Garver Lamme Award, the ACM Eckert-Mauchly Award, the Seymour Cray Computer Engineering Award, an NEC C&C Prize for lifetime achievement in computer science and engineering, a Founders Award from the American Academy of Arts & Sciences, and the IEEE Medal of Honor (IEEE's highest award). He is a member of the National Academy of Engineering and the National Academy of Sciences, and he is a Fellow of the Association for Computing Machinery and the Institute of Electrical and Electronics Engineers. He was elected a Fellow of the American Academy of Arts & Sciences in 1995.

Charles O. Holliday, Jr., is Chairman of the Board and Director of Bank of America, a Director of the Royal Dutch Shell PLC, and a Presiding Director of Deere & Company. He is the former Chairman of the Board of E. I. du Pont de Nemours and Company, a position he held from 1999 to 2009. He served as Chief Executive Officer of DuPont from 1998 to 2008. He joined DuPont in 1970 as an engineer and held various positions throughout his tenure of more than thirty years. In 1990, he was named Vice President and then President of DuPont's Asia Pacific operations. He became Senior Vice President in 1992 and Executive Vice President and a member of the Office of Chief Executive in 1995. He was elected to the National Academy of Engineering in 2004 and elected as its Chair in 2012. He chaired the National Research Council Committee on Research Universities, and he served as a member on the NRC Committee on America's Climate Choices; the Committee on Prospering in the Global Economy of the 21st Century: An Agenda for American Science and Technology; and the Roundtable on Scientific Communication and National Security. He is a member of the Presidents' Circle, Chairman Emeritus of Catalyst, and Chairman Emeritus of the U.S. Council on Competitiveness. He is a founding member of the International Business Council. He has also received several honorary doctorates. He was elected a Fellow of the American Academy of Arts & Sciences in 2010.

Peter S. Kim is Professor of Biochemistry at Stanford University and member of Stanford ChEM-H, a new interdisciplinary institute bringing chemistry, engineering, and medicine together for human health. He served as President of Merck Research Laboratories from 2003 to 2013, during which time Merck gained approval for more than twenty new medicines and vaccines, including Januvia, Gardasil, Isentress, Zostavax, Rotateq, and Victrelis. Earlier, he was Professor of Biology at MIT, member of the Whitehead Institute, and Investigator at the Howard Hughes Medical Institute. He has served on the National Institutes of Health AIDS Vaccine Research Committee, the Institute of Medicine Council, the American Academy of Arts & Sciences ARISE Committee, the National Academy of Sciences Committee on a New Biology for the 21st Century, the Global HIV Vaccine Enterprise Council, and the Board of Trustees of the Alfred P. Sloan Foundation. He currently serves on the Board of Scientific Governors of the Scripps Research Institute, the Scientific Advisory Board of the NIH Vaccine Research Center, and the Scientific Review Board of HHMI. He is a member of the National Academy of Sciences and the Institute of Medicine, and a Fellow of the American Association for the Advancement of Science, the Biophysical Society, and the American Academy of Microbiology. He was elected a Fellow of the American Academy of Arts & Sciences in 2008.

Dana Mead is Chairman Emeritus of the MIT Corporation, where he was Chairman from 2003 to 2010. He is currently on the Pardee RAND Graduate School Board of Governors, and is Chair of the Advisory Council to the School for Public and Environmental Affairs at Indiana University. He has been a member of the Board of Directors for Pfizer, Zurich Financial Services, the Logistics Management Institute, the Center for Creative Leadership, and the JASON Foundation for Education. He has also been a Trustee of the George Marshall Foundation Board and a member of the Council on Foreign Relations. Previously, he served as Chair and CEO of Tenneco, and Chair of the National Association of Manufacturers and the Business Roundtable. He served for twenty-five years as a Presidential Commissioner on White House Fellowships and is a Lifetime Trustee and Cochair of the bicentennial fund drive of West Point's Association of Graduates. He also served on the Executive Advisory Committee of the Center for Risk Analysis at the Harvard School of Public Health. He has received numerous awards, including the Distinguished Citizen Award from the Boy Scouts of America, the Woodrow Wilson Award from the Wilson Foundation, the McCloy Award from the American Council on Germany, the Manufacturing Leadership Award from the National Association of Manufacturers, the John W. Gardner Legacy of Leadership Award from the White House Fellows Association, the Eisenhower Award from Business Executives for National Security, and the Bronze Beaver, MIT's highest alumni award. He was elected a Fellow of the American Academy of Arts & Sciences in 2009.

Richard A. Meserve is President Emeritus of the Carnegie Institution for Science. He served as President of Carnegie from 2003 to 2014, following a term as Chairman of the U.S. Nuclear Regulatory Commission. Previously, he was a partner in the Washington, D.C., law firm Covington & Burling LLP, where he now serves on a part-time basis as Senior Of Counsel. Earlier in his career he served as law clerk to Supreme Court Justice Harry A. Blackmun and as legal counsel to the President's Science Advisor. His expertise in applied physics and law has enabled him to serve on or chair numerous committees involving legal/technical issues, including many convened by the National Academy of Sciences and the National Academy of Engineering. Among other activities, he is the Chairman of the International Nuclear Safety Group (chartered by the International Atomic Energy Agency); a member of the National Academy of Engineering, serving on its council; a member of the American Philosophical Society; and a Foreign Member of the Russian Academy of Sciences. He is a Fellow of the American Physical Society and the American Association for the Advancement of Science. He was elected a Fellow of the American Academy of Arts & Sciences in 1994, and serves on its Council and Trust. He is also a member of the Advisory Committee to the Academy's Global Nuclear Future Initiative.

C. D. Mote, Jr., is President of the National Academy of Engineering and Vice Chair of the National Research Council. He is former President of the University of Maryland and Regents Professor & Glenn L. Martin Institute Professor of Engineering. He previously served as Vice Chancellor at the University of California, Berkeley, and held the FANUC Chair in Mechanical Systems. He has held numerous positions on government committees, including Vice Chair of the Review Committee for Department of Defense Basic Research and Cochair of the Government-University-Industry Research Roundtable. His research has focused on the dynamics of gyroscopic systems and biomechanics. He is a member of the National Academy of Engineering and a recipient of its Founders Award. He is also an Honorary Member of the American Society of Mechanical Engineers International and a Fellow of the International Academy of Wood Science, the American Academy of Mechanics, the Acoustical Society of America, and the American Association for the Advancement of Science. He was elected a Fellow of the American Academy of Arts & Sciences in 2004.

Venkatesh "Venky" Narayanamurti is Director of the Science, Technology, and Public Policy Program at the Belfer Center for Science and International Affairs at the Harvard Kennedy School. He is also the Benjamin Peirce Professor of Technology and Public Policy and a Professor of Physics at Harvard University. From 1998 to 2008, he served as Dean of the Division (and then School) of Engineering and Applied Sciences at Harvard University. From 2003 to 2006, he was concurrently Dean of Physical Sciences. He spent much of his scientific career at Bell Laboratories, where he became Director of Solid State Electronics Research in 1981. He has served on numerous advisory boards in the federal government, in research universities, and in the private sector. He was elected a Fellow of the American Academy of Arts & Sciences in 2007 and serves as a member of the Academy's Board of Directors and Council. He is also a Codirector of the Academy's ARISE II project (Advancing Research In Science and Engineering: The Role of Academia, Industry, and Government in the 21st Century).

Maxine L. Savitz is the retired General Manager of Technology Partnerships at Honeywell, Inc. During her time at Honeywell, she oversaw the development and manufacturing of innovative materials for the aerospace, transportation, and industrial sectors. From 1979 to 1983, she served as Deputy Assistant Secretary for Conservation in the U.S. Department of Energy. She served two terms as Vice President of the National Academy of Engineering from 2006 to 2014. She serves on advisory bodies for the Sandia National Laboratory and Pacific Northwest National Laboratory, and is a member of the Board of Directors of the American Council for an Energy Efficient Economy. She served on the National Academy's Committee on America's Energy Future and was Vice Chair of the Energy Efficiency Committee. She is Co–Vice Chair of the President's Council of Advisors for Science and Technology. She was elected a Fellow of the American Academy of Arts & Sciences in 2013 and cochairs the Academy's Alternative Energy Future project.

Robert F. Sproull is Adjunct Professor of Computer Science at the University of Massachusetts, Amherst. He recently retired as Director of Oracle Corporation's Oracle Labs, acquired from Sun Microsystems. Earlier he was Associate Professor of Computer Science at Carnegie Mellon University. He cofounded Sutherland, Sproull and Associates, a consulting firm that became part of Sun Microsystems Laboratories. He is a member of the National Academy of Engineering and has served on the U.S. Air Force Scientific Advisory Board. He currently chairs the National Research Council's Computer Science and Telecommunications Board (CSTB) and is a Director of Applied Micro Circuits Corporation. He has coauthored several books, including *Principles of Interactive Computer Graphics* and *Logical Effort*. He was elected a Fellow of the American Academy of Arts & Sciences in 2002.

Subra Suresh is the President of Carnegie Mellon University. He is the only university president and one of only sixteen living Americans to be elected a member of all three branches of the United States National Academies (Engineering, Sciences, and Medicine). Nominated by the President of the United States, Suresh previously served as Director of the National Science Foundation, where he led the creation of the NSF Innovation Corps, the Global Research Council, and the Graduate Research Opportunities Worldwide initiative. Prior to his work at the NSF, Suresh was Dean and Vannevar Bush Professor of Engineering at MIT. His research into the properties of engineered and biological materials and their connections to human diseases – published in about three hundred articles and three books and represented by twenty-one patents – has shaped many disciplines and technologies. Suresh has been elected to fourteen academies based in the United States, China, India, Sweden, Germany, Italy, and Spain. He has been awarded eleven honorary doctorate degrees from institutions in the United States, Europe, and Asia. He was also the recipient of the 2013 Benjamin Franklin Medal in Mechanical Engineering and Materials Science from the Franklin Institute, and of the Padma Shri award, one of the highest civilian honors in the Republic of India, from the President of India in 2011. He was elected a Fellow of the American Academy of Arts & Sciences in 2004.

Shirley M. Tilghman was elected Princeton University's nineteenth President in 2001. She served on the Princeton faculty for fifteen years before being named President. During her tenure the university expanded its undergraduate and graduate student bodies and instituted a four-year college system. She oversaw the creation of major new academic programs, including the Princeton Neuroscience Institute, the Andlinger Center for Energy and the Environment, and the Lewis Center for the Arts. Upon the completion of her term in June of 2013, she returned to the faculty, and she now serves as Professor of Molecular Biology and Public Policy. During her scientific career as a mammalian developmental geneticist, she studied the way in which genes are organized in the genome and regulated during early development. A member of the National Research Council committee that set the blueprint for the United States effort in the Human Genome Project, she was also one of the founding members of the National Advisory Council of the Human Genome Project for the National Institutes of Health. She was appointed a Howard Hughes Medical Institute Investigator in 1988, and in 1998 was named the Founding Director of Princeton's multidisciplinary Lewis-Sigler Institute for Integrative Genomics. She is the recipient of a Lifetime Achievement Award from the Society for Developmental Biology, the Genetics Society of America Medal, and the L'Oreal-UNESCO Award for Women in Science. She is a member of the American Philosophical Society, the National Academy of Sciences, the Institute of Medicine, and the Royal Society of London. She serves as a Trustee of the Carnegie Endowment for International Peace and the King Abdullah University of Science and Technology, and as a Director of Google Inc. She was elected a Fellow of the American Academy of Arts & Sciences in 1990.

Jeannette Wing is Corporate Vice President at Microsoft Research and head of all the organization's research laboratories worldwide. She joined Microsoft Research in January 2013. From 2007 to 2010, she was Assistant Director of the Computer and Information Science and Engineering Directorate at the National Science Foundation. Wing served twice as Head of the Department of Computer Science at Carnegie Mellon University (CMU), where she is now the President's Professor of Computer Science (on leave). She was also Associate Dean for Academic Affairs at Carnegie Mellon for five years. Wing served as the Founder and Director of the Center for Computational Thinking at Carnegie Mellon. Prior to CMU, she was on the faculty at the University of Southern California for two years, and as a student, worked at Bell Laboratories and Xerox PARC. She is incoming Chair of DARPA ISAT. Her areas of expertise are trustworthy computing, formal methods, concurrent and distributed systems, programming languages, and software engineering. Wing received the CRA Distinguished Service Award in 2011 and the SIGSOFT Retrospective Paper Award in 2012. She is a Fellow of the American Association for the Advancement of Science, the Association for Computing Machinery, and the Institute of Electrical and Electronic Engineers. She was elected a Fellow of the American Academy of Arts & Sciences in 2010.

Elias Zerhouni is President of Global Research and Development for Sanofi and a member of its Executive Committee. A physician-scientist and world-renowned leader in radiology research, he earned his medical degree from the University of Algiers in 1975 before coming to the United States. After completing his residency in diagnostic radiology at Johns Hopkins as Chief Resident, he rose to the rank of Professor of Radiology and Professor of Biomedical Engineering. In 1996, he was named Director of the Department of Radiology. He then assumed additional duties as Vice Dean for Clinical Affairs and President of the Johns Hopkins Clinical Practice Association, Vice Dean for Research, and Executive Vice Dean for the Johns Hopkins University School of Medicine until his nomination as the fifteenth Director of the National Institutes of Health by the President of the United States. During his seven-year tenure, he led the NIH through a challenging period requiring innovative solutions to transform clinical research into tangible benefits for patients. One of the hallmarks of his tenure is the NIH Roadmap for Medical Research, which brought together all of the NIH's twenty-seven institutes and centers, with more than 18,000 employees and a budget of $29.5 billion, to fund research initiatives that could have a major impact on science. He authored more than two hundred publications and holds a number of prominent positions on several boards, including the Boards of the Lasker Foundation and Research America. He chaired many committees such as the Clinical Practice Association Board of Governors and the Scientific Advisory Council. President Obama appointed Zerhouni as one of the first U.S. Science Envoys (2009). He has been a member of the Institute of Medicine of the National Academies since 2000, was elected in 2010 as a member of the French Academy of Medicine, and was appointed as Chair of Innovation at the College de France in 2011. In 2013, he was elected as a member of the U.S. National Academy of Engineering and the French Academy of Technologies.

Appendix B: What has Changed Since Vannevar Bush? A Brief History of American Research, 1945 to Today

SCIENTIFIC RESEARCH AS SCIENTIFIC CAPITAL: VANNEVAR BUSH'S *SCIENCE, THE ENDLESS FRONTIER*

As World War II neared its conclusion, Dr. Vannevar Bush, wartime science advisor to President Franklin Delano Roosevelt and Director of the Office of Scientific Research and Development, received a letter from the President (dated November 17, 1944) with an extraordinary request.

Roosevelt was keenly aware that the unprecedented research partnership established early in the war between the federal government and the nation's leading universities had been critical to America's victory. In his letter, Roosevelt refers to OSRD and the government-university partnership as a "unique experiment of teamwork and cooperation in coordinating scientific research and in applying existing scientific knowledge to the solution of the technical problems paramount in war." He continues: "There is no reason why the lessons to be found in this experiment cannot be profitably employed in times of peace." In his letter, Roosevelt asks Bush to recommend actions that the federal government could take to accomplish that objective. In particular, he asks what programs might be devised for "continuing the work already being done in medicine and related sciences" and "discovering and developing scientific talent in America." More generally, the President poses: "What can the Government do now and in the future to aid research activities by public and private organizations?"[177]

President Roosevelt died on April 12, 1945, before Bush could submit his final report. But on July 25, 1945, Bush wrote a letter to President Truman to accompany his completed report *Science, The Endless Frontier*, which has become an iconic piece of American science policy. In the letter, Bush concludes:

> The pioneer spirit is still vigorous within this nation. Science offers a largely unexplored hinterland for the pioneer who has the tools for his task. The rewards of such exploration both for the Nation and the individual are great. Scientific progress is one essential key to our security as a nation, to our better health, to more jobs, to a higher standard of living, and to our cultural progress.[178]

In his brief report, Bush addresses the importance of science to national security, health and medicine, and the public's well-being, emphasizing that "one of our hopes is that after the war there will be full employment," which will require "plenty of new, vigorous enterprises." Still, he emphasizes that "new products and processes are not born full-grown. They are founded on new principles and new conceptions which in turn result from basic scien-

177. Franklin D. Roosevelt to Vannevar Bush, November 17, 1944, Washington, D.C., https://www.nsf.gov/od/lpa/nsf50/vbush1945.htm.

178. Bush, *Science, The Endless Frontier*, vi.

tific research. . . . Clearly, more and better scientific research is one essential to the achievement of our goal of full employment."[179]

Bush refers to scientific research as "scientific capital," expressing his view that the funding of research should be considered not as a cost but as an investment in America's future, its economy, and the well-being of its citizens (a view that has been confirmed by leading economists who have studied the issue).

Bush is specific about what it takes to increase scientific capital:

> First, we must have plenty of men and women trained in science, for upon them depends both the creation of new knowledge and its application to practical purposes. Second, we must strengthen the centers of basic research, which are principally the colleges, universities, and research institutes. These institutions provide the environment which is most conducive to the creation of new scientific knowledge and least under pressure for immediate, tangible results. With some notable exceptions,[180] most research in industry and Government involves application of existing scientific knowledge to practical problems. It is only the colleges, universities, and a few research institutes that devote most of their research efforts to expanding the frontiers of knowledge.[181]

It is remarkable how well this recipe for scientific capital still characterizes the situation nearly seventy years after the report was written. For decades, the recipe worked, and led to many of America's universities being ranked among the best in the world. Their research output and graduates have gone on to create new industries, jobs, and wealth; they also continue to seed university faculties with many of the nation's top scientists and engineers who join the academic ranks and keep the enterprise strong.

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179. Ibid., 2.

180. Examples of such "notable exceptions" include General Electric (GE), E. I. du Pont de Nemours and Company (DuPont), and AT&T, which engaged in important partnerships with the government on critical technology initiatives – from radar to artificial rubber – during the war.

181. Bush, *Science, The Endless Frontier*, 2. Bush is often criticized by scholars for advancing "linear" arguments to make his case, posing that curiosity-driven basic research would lead to applied research on promising discoveries and to the development of products that would make their way to the market, in turn creating businesses, wealth, and jobs. Clearly, innovation is more complicated than this. But perhaps Bush felt that 1945 was not the time for complicated arguments about science, particularly in discussions with the President and Congress. Of course, much more is known about innovation now than was the case immediately after World War II.

"NEW PRODUCTS AND PROCESSES ARE NOT BORN FULL-GROWN": A NEW ERA OF FEDERAL INVESTMENT IN BASIC SCIENCE RESEARCH

The Road to the National Science Foundation

Bush's report took a principled stance, but it also includes detailed recommendations about how to accomplish the objectives laid out in President Roosevelt's letter. In the chapter "The Means to the End," Bush proposes a mechanism to accomplish the objectives outlined earlier in his report. He proposed a new federal agency, the National Research Foundation (NRF), which would fund all fields of basic research, including medical and long-range military research, as well as advanced scientific education. He argued that the new agency should be "independent" – in other words, not under an "operating agency" that has major responsibilities in areas other than science – stating that "research will always suffer when put in competition with operations."[182] He argued that a single agency was best, since it would permit the flow of scientific knowledge across traditional disciplinary boundaries (for example, from chemistry to medicine). The NRF would accept unsolicited proposals from host universities, employ expert peer reviewers to evaluate the merits of the proposals, and then award grants to the selected universities, which would be responsible for grant management. The new agency would not replace the existing research programs in the Departments of Agriculture, Commerce, Interior, or other operating agencies, where research was (and still is) largely focused on applied research to address particular national needs. The NRF would instead emphasize fundamental research that is not directed toward any particular application and is not supported by industry. Bush argued that the NRF should also support basic defense research, while leaving the services in charge of applied research and development focused on the improvement of weapons systems.

Bush described five "fundamentals" that he felt were critical to the success of the new organization: 1) funding should remain stable over a period of years so that long-range programs may be undertaken; 2) the agency should consist of citizens selected only on the basis of their interest and expertise; 3) the agency should support research outside of government and not operate its own laboratories; 4) research supported in colleges, universities, and research institutes should leave the internal control of policy, personnel, and the method and scope of the research to the institutions themselves; and 5) the agency must be responsible to the President and Congress.

According to Bush, the structure of the NRF would consist of divisions of medical research; research in the physical and natural sciences; long-range military research; scientific personnel and education; and publications and scientific collaboration (especially international collaboration).

182. Ibid., 26.

He also proposed a purpose or mission for the NRF:

> The National Research Foundation should develop and promote a national policy for scientific research and scientific education, should support basic research in nonprofit organizations, should develop scientific talent in American youth by means of scholarships and fellowships, and should by contract and otherwise support long-range research on military matters.[183]

Finally, he suggested that the NRF be governed by a board of uncompensated members who would be appointed by the President and who would themselves select a chairman and director.

When President Truman read the report, his reaction (especially to the governance recommendations) was negative, which led to a period of discussion. But while those matters were being debated, the post–World War II American science landscape was changing rapidly. Several federal agencies were growing their research budgets, including portions for basic research. In Congress, Senator Harley M. Kilgore (Democrat, West Virginia) had his own model for a research agency, which he called the National Science Foundation and which differed considerably from Bush's NRF.

Vannevar Bush's NRF was never realized. But in 1950, the National Science Foundation was established. It was a pale reflection of Bush's NRF, and Bush did not hide his disappointment. The NSF had a very small budget and no responsibilities for medical or defense research. Its governance consisted of a director and a National Science Board, each appointed by the President and confirmed by the Senate. The NSF authorizing legislation simply states: "The [National Science] Foundation shall consist of a National Science Board . . . and a Director." It was given a mission "to advance the national health, prosperity, and welfare; and to secure the national defense." More specifically, it was directed to "initiate and support: basic scientific research and research fundamental to the engineering process; programs to strengthen scientific and engineering research potential; science and engineering education programs at all levels and in all the various fields of science and engineering; programs that provide a source of information for policy formulation; and other activities to promote these ends."[184]

While the NSF is not the kind of agency Bush had in mind, it has (after a slow start) nevertheless served the nation well. With a total annual operating budget of about $7 billion, it is responsible for vital financial support for American academic basic research in most disciplines of science, including the social sciences and engineering,[185] and it is viewed across the globe as a model of how government can best support basic research. On the other hand, over

183. Ibid., 28.

184. *National Science Foundation Act of 1950*, Public Law 81-507, 81st Congress (May 10, 1950).

185. Excluding medical and military research.

the years, the NSF has been handed new responsibilities through the Congressional reauthorization process. Although the agency's budget has grown, it has been stretched to meet its obligations and has subsequently moved further away from focusing strictly on fundamental research, a principle that Vannevar Bush felt was critical. The same observation can be made about other federal agencies that support research. For example, some have argued that the NIH should support more translational research.

The reason for recounting this history is not to single out one agency, but rather to recall the original objectives Vannevar Bush had in mind and provide a historical context for how the nation, especially the federal government, handles research funding in today's changed world. The question of the proper balance between truly fundamental research (conducted with no possible application in mind) and "use-inspired" research[186] (carried out with a potential application in mind) is actively debated for all federal research agencies.

AN UNCOORDINATED SYSTEM OF FEDERAL RESEARCH SUPPORT – BORN AT THE END OF WORLD WAR II AND FUELED BY COLD-WAR POLITICS

In the five years it took to get the NSF in place, several other research funding agencies were created: the National Institutes of Health in 1948 (although parts of the NIH had much earlier origins); the Office of Naval Research in 1946 (although the Naval Research Laboratory dates to 1923); and the Atomic Energy Commission in 1946, which in 1975 split into the Nuclear Regulatory Commission and the Energy Research and Development Administration (ERDA, later the Department of Energy). Federal R&D funding began to grow, and these agencies established their roots firmly in the American science and technology system. Moreover, all these agencies supported basic research, often using a competitive process in which expert peer review was used to guide the agencies' decisions on which proposals to fund. Thus, when the NSF was finally created in 1950, much of the federal research portfolio had already been set in place.

From an academic researcher's perspective, having several agencies positioned to support research was a benefit. What one agency – or rather the experts who reviewed the research proposals for that agency – might not find appealing might be squarely in another agency's wheelhouse. In physics, for example, a faculty member might have grants or contracts with the DOE, NSF, and ONR all at the same time – perhaps not for the same project, but certainly for

186. Donald E. Stokes, *Pasteur's Quadrant – Basic Science and Technological Innovation* (Washington, D.C.: Brookings Institution Press, 1997).

related activities. In such cases, the knowledge gained from the NSF work often would inform the DOE or ONR projects, and vice versa.

During and after the war, much of the nation's federal R&D, particularly applied research and development, was performed by industry and national laboratories, including those operated directly by federal agencies: for example, the NIH intramural laboratories and NASA centers, and the Federally Funded R&D Centers (FFRDCs) operated for government by universities and other non-federal organizations. During the Cold War, the missions and activities of many of these laboratories, especially those supported by the DOD and the DOE, were tied to national security interests. In more recent decades, their missions have become less clear, raising difficult policy questions.

Large corporations were also putting their own money into R&D, and major discoveries were being made by industrial researchers. AT&T's Bell Laboratories developed the transistor, demonstrated in 1947 by John Bardeen, Walter Brattain, and William Shockley (who shared the 1956 Nobel Prize in Physics). Jack Kilby of Texas Instruments demonstrated the integrated circuit in 1958 (and won the 2000 Nobel Prize in Physics). In 1960, the first laser was demonstrated by Theodore Maiman of Hughes Research Laboratories, although in 1958 Bell Labs had received a patent for the proposed "optical maser" based on the work of Charles Townes and Arthur Schawlow.[187] These large industrial R&D laboratories that merged basic discovery and practical application under one roof are often held up as shining examples of the process of innovation. Bell Labs in particular not only developed the transistor and the laser, but also the charge-coupled device (CCD); the UNIX operating system; the C, S, and C++ programming languages; information theory; and radio astronomy. With the disappearance of these institutions, collaboration between universities and industry has become especially important. While one can point to many examples of success, particularly in today's energy and pharmaceutical sectors, the industry-university partnership is still a work in progress.

187. The history of the invention of the laser is complicated and still debated. Many researchers made substantial contributions, including Soviet physicists Nikolay Basov and Aleksandr Prokhorov, who shared the Nobel Prize in Physics with Charles Townes in 1964. Schawlow shared the Nobel Prize in Physics in 1981 for his work in laser spectroscopy.

SCIENCE, ENGINEERING, AND TECHNOLOGY: PARAMOUNT IN WAR AND IN PEACE

Sputnik and Apollo – A Golden Age for American Science and Engineering

The Soviets' launch of the satellites Sputnik I (a twenty-three-inch sphere that "beeped") and Sputnik II (a thirteen-foot-long capsule containing an ill-fated dog, Laika) in October and November 1957 seemed to indicate that the United States was losing the space race. There was concern that if the USSR could put satellites in orbit, they must also have the missile-launch capability to deliver nuclear weapons to North America. Moreover, Sputnik signaled to many that the USSR had technologically outstripped the United States across the board. In response, President Eisenhower and Congress sharply increased R&D spending. In 1958, the national science and technology landscape changed, at least at the federal level: NASA was created to provide civilian control of the U.S. space effort; and the Advanced Research Projects Agency (ARPA) was established to support R&D focused on long-term military needs. By focusing on technologies that seemed most promising, ARPA (in some years DARPA – the *D* stands for *Defense*) partnered with universities and companies to promote rapid development. DARPA had particular impact in the areas of computing and networking: the first Internet, which was funded by the NSF, was based on the ARPANET platform. Also in 1958, Congress passed the National Defense Education Act (NDEA), which provided fellowships and low-interest loans to college and university students, as well as support to states to improve their teaching of science, math, and modern languages in K–12 schools.

In April 1961, only three months after John F. Kennedy became President, the USSR made another breakthrough, sending cosmonaut Yuri Gagarin into orbit and returning him safely to Earth. Kennedy, realizing that space had become a top priority, made the bold decision to attempt to send men to the moon and back within a decade, a feat he promised would be accomplished in a speech he delivered in the football stadium of Rice University in Houston, Texas, on September 12, 1962.[188] Kennedy understood that the challenge was not just to get to the moon before our Cold-War adversary, but to ensure that America was the unchallenged world leader in science and technology. Budgets for NASA's Apollo program, for civilian R&D, and for science and math education increased rapidly. Young men and women were excited by the possibility of careers in science and engineering. The government-university partnership that had formed during World War II and that Vannevar Bush recommended be strengthened after the end of the war was set firmly in place, in large part because of Sputnik and the Cold-War "win back the space race" politics that followed. Many look back on this period as

188. John F. Kennedy, "Address at Rice University," Houston, Texas, September 12, 1962, John F. Kennedy Presidential Library and Museum, http://www.jfklibrary.org/Asset-Viewer/Archives/JFKPOF-040-001.aspx.

the "golden age" of American science. Americans on the Apollo 11 mission first landed on the moon on July 20, 1969: earlier than Kennedy had expected, but six years after his assassination on November 22, 1963.

During the 1960s and 1970s, the intensity of the focus of American policy-makers and the American people on science waned, although American science made considerable progress during this period. President Nixon's war on cancer drove fundamental biomedical research that unearthed a trove of new knowledge on the nature and origins of cancer and propelled advancements in treatments for and prevention of the disease. The successes of the NIH Associate Training Program and their "yellow-beret" uniformed investigators marked what is considered by some to be the height of NIH intramural influence.[189] Still, the United States' involvement in the Vietnam War, which escalated dramatically throughout the decade – resulting in the deaths of over fifty thousand Americans and more than a million Vietnamese, Cambodians, and Laotians – became increasingly unpopular with the American public. The war was a particular source of tension between university faculty and students on campuses across the country and President Lyndon Johnson. At the same time, considerable social unrest was sweeping the country. While the Cold-War argument for continued investment in research was still strong, there was little enthusiasm in Washington for sending money to academics who vocally expressed their opposing views. U.S. involvement in the war officially ended in 1973 with the "Case-Church Amendment."

Following the final moon landing of Apollo 17 in December 1972, the large cost of moon trips (Apollo is estimated to have cost about $100 billion in FY 2010 dollars), the thawing Cold-War climate, pressure from Congress to address a large number of domestic concerns, and a lessening of the public's enthusiasm for space travel caused President Nixon to cut back funding for NASA and human space travel. A new NASA faced a more narrow vision, smaller missions, and reduced budgets. One of the first projects in this new phase of NASA's history was Skylab, the first orbiting space station, which flew from 1973 to 1979.

As the Apollo program wound down, NASA focused on a second-generation Space Transportation System (STS) called the Space Shuttle, which had the capability to deliver people and heavy cargo to low earth orbit and back. The Shuttle flew 135 missions from 1981 to 2011 (including two shuttles that were tragically lost with their crews in catastrophic accidents: Challenger in 1986 and Columbia in 2003). Those missions delivered satellites to orbit; carried astronauts, supplies, and equipment to the International Space Station (ISS); and placed the Hubble Space Telescope in its orbit and carried out repair and upgrade missions.

189. Melissa K. Klein, "The Legacy of the 'Yellow Berets': The Vietnam War, the Doctor Draft, and the NIH Associate Training Program," Manuscript, Office of NIH History (Bethesda, Md.: National Institutes of Health, 1998).

In 1972, President Nixon and Soviet Premier Alexei Kosygin signed a cooperative space agreement that specified that U.S. and USSR spacecraft would be able to dock in space, thus launching the Apollo-Soyuz Test Project. As it turned out, this cooperation ultimately made it possible for the United States and Russia (following the collapse of the USSR) to partner with other nations in building the ISS, starting with the launch of the first module in 1993. Had Nixon and Kosygin not reached this agreement, America likely would have been without transportation to and from the ISS at various times, such as when the shuttle fleet was grounded following accidents, and, of course, now that the program has been terminated.

Much of what the American people know about NASA has to do with human spaceflight. But NASA science beyond manned missions – most of it robotic exploration – has also been spectacular, from the planetary missions (the *Curiosity* rover relentlessly traverses the Martian landscape) to solar physics to space-based telescopes (the Hubble Space Telescope has helped fundamentally change our conception of the universe) to earth-observing satellites that help us understand weather, climate change, and human impact on Earth's surface. Furthermore, along with several other federal agencies, NASA has supported research on university campuses in a variety of fields.

It is appropriate to single out NASA's role in promoting science, engineering, and technology during this period of U.S. history for at least two reasons. First, the Apollo era was the only time in the nation's history when such large federal investments[190] were made in a non-military activity, notwithstanding its Cold-War rationale. It is therefore important to understand what was done with that money and how it influenced the public's attitude about science and technology and related government policy. Second, the Apollo program energized young people to study science and math and become the scientists and engineers who helped the United States become an unchallenged world leader in science and technology.

During the early years of the Cold War, research in the physical sciences and engineering remained a high priority, as it had been during World War II. Universities grew their faculty numbers in these fields and invested in infrastructure to help the faculty carry out their research and attract federal grants to support both their work and graduate and postdoctoral students. In physics departments, nuclear physics and, over time, high-energy particle physics were priorities. As the need for higher-energy beams grew, so did the cost, until only a few national laboratories (such as Fermilab, Argonne, and Brookhaven) and university laboratories (such as the Stanford Linear Accelerator Center and Cornell's Wilson Laboratory) could afford to build and maintain the machines. Along the way, synchrotron radiation, originally an unpleasant byproduct of bending high-velocity charged particle beams, became an essential instrument for studying both physical and biological materials. During this time, so-called small science, such as

190. Relative to the total federal discretionary budget.

condensed matter and atomic and molecular physics, found favor in many departments. Physics received most of its support from the DOE and NSF. Even today, the DOE Office of Science is the largest federal funder of basic research in the physical sciences.[191] Engineering was largely funded by the DOE and DOD. Chemistry was funded by several agencies, as were mathematics and computer science. Astronomy and astrophysics were supported by NASA (which focused on space-based telescopes and theory) and the NSF (which focused on land-based telescopes and theory). The life sciences and social sciences were supported by the NSF and several other agencies, including the NIH, which focused on biomedical research.

THE COLD WAR AND BEYOND: A GOLDEN AGE FOR AMERICAN MEDICAL SCIENCE

"We cannot be a strong nation unless we are a healthy nation. And so we must recruit not only men and materials but also knowledge and science in the service of national strength."

– Franklin D. Roosevelt, Address at the Dedication of the National Institute of Health, October 31, 1940[192]

During the Cold War, substantial defense spending for R&D, coupled with the urgency of maintaining a technological lead in every area of science and technology, prompted many of the nation's most capable scientists to devote their careers to research supporting national security. The result was that in many disciplines, the leading edge of discovery was to be found in defense-related research. The list of contributions to civilian life that resulted from this research is long and significant, including the Internet, GPS, weather satellites, jet engines and modern aircraft, practicable helicopters, commercial nuclear power, earth observation satellites, and communications satellites.

With the end of the Cold War, spending for defense R&D and the exigency of the mission waned, with the result that many of the firms in the national security enterprise transformed into systems integrators as opposed to creators of knowledge. During the same period, market pressure for short-term profits grew throughout U.S. industry, such that firms downsized or closed their research laboratories altogether and focused whatever resources remained on applied research.

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191. U.S. Department of Energy Office of Science, "About," http://science.energy.gov/about/.

192. Franklin D. Roosevelt, "Address at the Dedication of the National Institute of Health," October 31, 1940, *The American Presidency Project*, http://www.presidency.ucsb.edu/ws/?pid=15888.

After the peak excitement of the Apollo moon landings and an unprecedented period of strong political and financial support for federal R&D, including basic research at universities, most federal agencies adjusted to less ambitious funding levels (Figure 12, page 131). While the DOE saw large increases in R&D funding during the oil crises of 1973 and 1979, little of that went to support basic research, and once the crises ended, the budgets were again reduced.

The bold effort to build the largest and most powerful particle accelerator in the world, the Superconducting Super Collider (SSC), at a site near Dallas, Texas, faltered when Congress voted to shut it down in 1993 – after a few billion dollars of federal and Texas money had already been spent.[193] There were several reasons advanced for this decision, including the high price tag, cost escalation, management issues, and lack of international partners. But for those who felt that large physics projects of this kind were Cold-War relics, the decision was, perhaps, not surprising. One lesson from this moment in the history of U.S. science is that the money saved by canceling the project did not go into science, at least not in any way that could be tracked.

Biomedical research was the one exception to the ups and downs of R&D funding in the decades following the wind-down of Apollo. The NIH budget saw nearly steady real growth year after year, actually doubling between 1998 and 2003 (Figure 13, page 132), bolstered by the effective advocacy of dozens of science- and disease-oriented societies.

193. Alan Ehrenhalt, "Learning from the Fifties: Science at Risk," *Wilson Quarterly* 19 (3) (Summer 1995): 1 – 162.

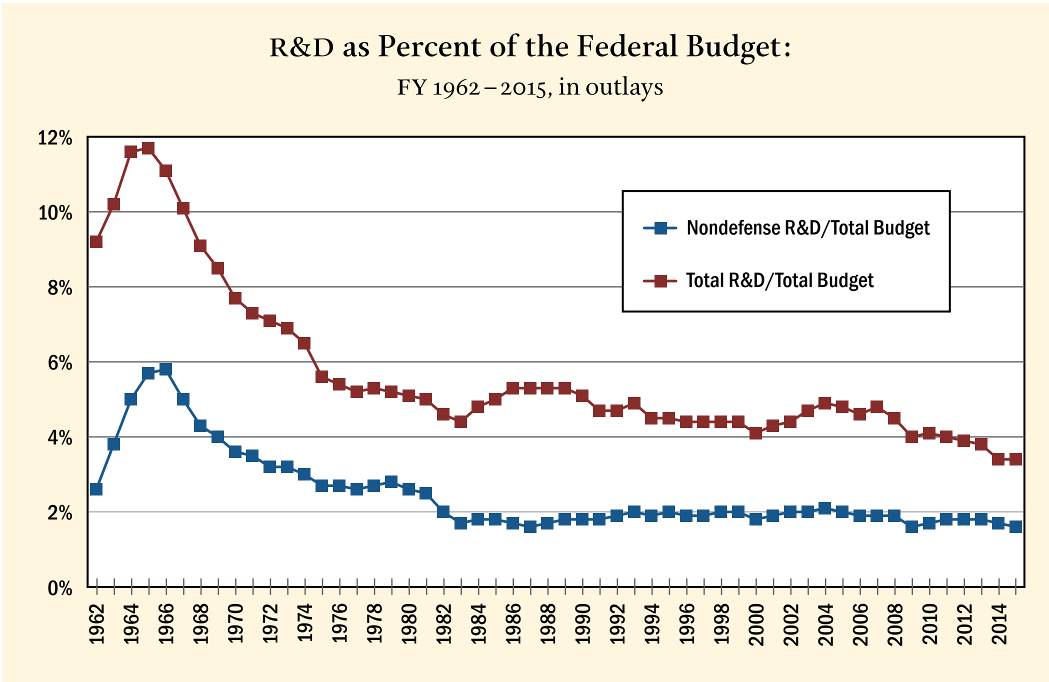

Figure 12

Federal R&D Investment as a Percent of the Federal Budget, 1962 – 2015

Source : The above figure is a recreation of a figure published in the American Association for the Advancement of Science, *AAAS Report XXXVII : Research and Development FY 2013* (New York : American Association for the Advancement of Science, 2012). See also the Office of Management and Budget, *Fiscal Year 2015 Budget of the U.S. Government Historical Tables* (Washington, D.C. : Office of Management and Budget, 2014).

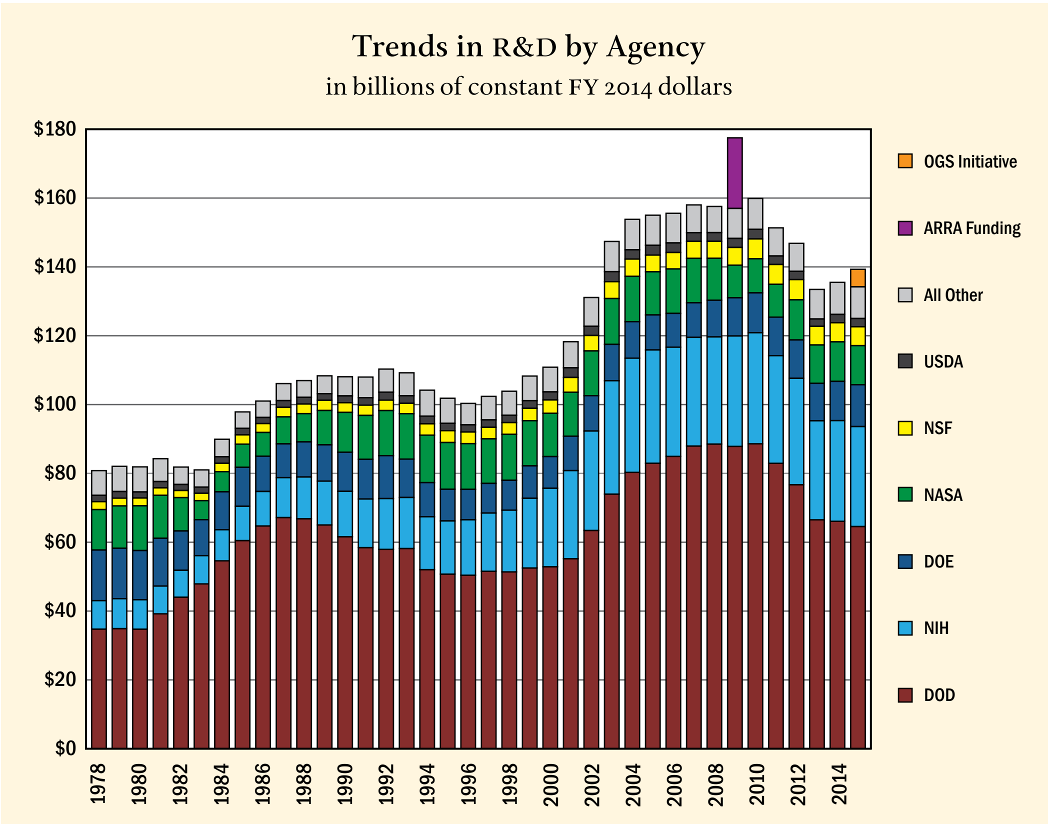

Figure 13

Federal Agencies' Investments in R&D, 1978 – 2015

Source: The American Association for the Advancement of Science, *AAAS Report XXXVII: Research and Development FY 2013* (New York: American Association for the Advancement of Science, 2012).

There is nothing to suggest that the nation, the President, or Congress had developed a strategy to deliberately shift priorities and funding from space (and R&D in the physical sciences and engineering) to biomedical research. NASA and the NIH are in different appropriations subcommittees, each with sharply defined jurisdictions. However, the Apollo budgets were large, so cutting NASA funding back left room in future budgets for presidents and Congresses to fund other priorities.

The National Cancer Act of 1971, signed by President Nixon, was the beginning of the war on cancer.[194] And as other diseases began to get more attention from the NIH, the public seemed to accept the premise that increased spending on biomedical research would win the "war on disease," just as early Cold-War investments in R&D (especially the Apollo Program) had won the war against communism. From 1978 to 1998, the NIH budget increased by an average of 8.4 percent per year, representing 4 percent per year of real growth.[195]

While it is difficult to establish the precise impact of NIH funding of biomedical research on the overall health of the nation (or even the world), the investment in research on heart disease, cancer, stroke, and diabetes has nonetheless had a visible and significant effect on the health of the U.S. population. It has been estimated that, between 1950 and 2004, about 35 million deaths caused by the aforementioned diseases were avoided due to NIH investments in biomedical research.[196] Large increases in the NIH budget from 1956 to 1967 were closely followed by declines in the rate of deaths due to heart disease and stroke. The war on cancer propelled a spike in funding for the National Cancer Institute, and beginning in 1991, following a series of groundbreaking discoveries in the treatment and origins of cancer, total cancer rates dropped precipitously.[197]

Around the same time, the National Center for Human Genome Research, now the National Human Genome Research Institute, released a research plan titled *Understanding Our Genetic Inheritance: The Human Genome Project, The First Five Years, FY 1991 – 1995*.[198] This marked the beginning of a decade-long research effort to sequence at least 90 percent of the human

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194. *National Cancer Act of 1971*.

195. NIH Office of Budget, "Appropriations History by Institute/Center (1938 to Present)," http://officeofbudget.od.nih.gov/approp_hist.html; and American Association for the Advancement of Science, R&D Budget and Policy Program, "Trends in R&D by Agency, 1976 – 2015," *Historical Trends in Federal R&D*, http://www.aaas.org/page/historical-trends-federal-rd (accessed August 15, 2014).

196. Kenneth G. Manton, Xi-Liang Gu, Gene Lowrimore, Arthur Ullian, and H. Dennis Tolley, "NIH Funding Trajectories and Their Correlations with U.S. Health Dynamics from 1950 to 2004," *Proceedings of the National Academy of Sciences* 106 (27) (2009): 10981 – 10986.

197. Ibid.

198. National Human Genome Research Institute, "An Overview of the Human Genome Project," https://www.genome.gov/12011239.

genome,[199] ushering in a new era of biology that leverages powerful genetic techniques (such as recombinant DNA technology) to explore life and disease states at scales from whole organisms to single cells.

At that point, Congress decided to double the NIH budget over a period of five years between 1998 and 2003. Congressman John Porter (Republican, Illinois), who was Chairman of the Appropriations Subcommittee on Labor, Health and Human Services, and Education, led the doubling effort, which garnered bipartisan support in both the House and Senate. Porter has said that if he had had all science within his subcommittee's jurisdiction he would have attempted to double other research budgets as well.[200] The five-year doubling period extended past the end of the Clinton administration and into the early years of the George W. Bush administration.

However, at the end of the NIH budget's doubling, competing national priorities caused enthusiasm for further increases to wane. This raised a number of policy issues, especially as many institutions continued to plan and build new facilities on the assumption of continued budget increases. The American Recovery and Reinvestment Act of 2009 provided a one-time boost of $10 billion to the NIH, and while the money was a tremendous boon to the biomedical enterprise, it also continued previous problems of funding unpredictability. This resulted in unfunded projects once the money ran out, and placed a heavy burden on the academic community. Finally, with the departure of some of its biggest supporters (Porter and Arlen Specter among them) NIH funding suffered and increasingly focused on short-term gains over long-term investment.

WHERE ARE WE TODAY, MORE THAN A DECADE INTO THE TWENTY-FIRST CENTURY?

Unquestionably, America's investments in science and engineering R&D during World War II and the early years of the Cold War positioned the nation as the unchallenged leader in science and technology in the twentieth century. Many American universities occupied the top tier of global higher education. Federal agencies that supported basic research, and in particular their use of a competitive grants process of awards based on expert peer review, were looked to as models of best practices. The annual Nobel Prize announcements routinely

199. International Human Genome Sequencing Consortium (Eric S. Lander et al.), "Initial Sequencing and Analysis of the Human Genome."

200. John Porter, private communication to Neal Lane.

included American scientists (though many of them were born in other countries).[201] Many graduates of American universities, particularly those on the East and West Coasts, took their knowledge and entrepreneurial skills to the marketplace, forming new companies like Genentech, Amgen, Biogen, Apple, Google, and, in earlier years, Hewlett-Packard and Xerox. Invariably, the fruits of basic research done on university campuses, funded largely by federal agencies, provided the building blocks that innovative companies could use to design products like laptops, iPods and iPads, smartphones, and other devices now in demand by billions of people. This relationship created jobs and infused the nation with wealth.

Vannevar Bush would likely point to these outcomes as affirmation of advice he gave the President in 1945: if the United States continues to invest in research, particularly basic research on university campuses, the nation and its people will benefit. But most Americans, including most members of Congress, may not understand the significance of the government-university partnership, and do not assume that federal dollars invested in basic research could – over time – create jobs and contribute to the nation's economy. That said, the American people (in some surveys, over 70 percent of them) have always held a positive view of science; and even if they do not know much science or understand the nature of research, they believe it is important. Most likely, they are influenced by advances in medicine, which many Congressional representatives connect, appropriately, with biomedical research funded by the NIH. The public's support for science was not lost on decades of political leaders who favored substantial growth of the NIH budget year after year for over three decades. While the NIH funds medical research, the NSF, DOE, DOD, NASA, NIST, and other agencies support innovation in medicine indirectly through research that creates knowledge and new technologies that benefit medical research (a point made by former NIH Director Harold Varmus). In fact, the impact of these organizations' research ultimately extends to almost every product or technological or medicinal advance people want or need. But while there were always champions of non-medical research in several administrations and Congresses, funding for the natural sciences[202] and engineering grew slowly or, for some agencies, not at all.

In 2003, even the argument that science should be a priority to win the "war on disease" seemed to be lost. Immediately after the doubling of the NIH budget, when most observers of science policy (as well as universities and medical schools that rely on robust levels of NIH funding) expected that the NIH would be back on a modest growth path, something surprising happened: neither the George W. Bush administration nor Congress requested significant increases for the agency. NIH funding has been in decline for over a decade, now having ret-

201. Jon Bruner, "American Leadership in Science, Measured in Nobel Prizes," *Forbes*, October 5, 2011, http://www.forbes.com/sites/jonbruner/2011/10/05/nobel-prizes-and-american-leadership-in-science-infographic/.

202. With the exception of biomedical research between 1997 and 2003.

rograded to 2010 levels and continuing to slip backward. From 2003 to 2014, the NIH budget fell by 2 percent on average each year, except for the large one-time $10 billion boost in FY 2009, as part of the American Recovery and Reinvestment Act (and that was largely the initiative of Senator Arlen Specter, who fought his own battles with cancer and eventually died of complications from non-Hodgkin's lymphoma in 2012). With many Americans facing serious medical problems in their families or circles of friends, one might expect the political process to respond accordingly.

The George W. Bush administration was not against funding research, but it had other priorities, especially following the September 11 terrorist attacks and the administration's decisions to wage war in Afghanistan and Iraq. But in his January 2006 State of the Union Address, President Bush announced his American Competitiveness Initiative (ACI),[203] which consisted of a $1.3 billion boost for research in the physical sciences and engineering and $4.6 billion in R&D tax incentives for FY 2007. Most likely, President Bush was responding to the long history of tepid funding for these fields, as well as the influential National Academies NRC report *Rising Above the Gathering Storm*.[204] The ACI called for doubling the budgets of the NSF, the DOE's Office of Science, and the NIST over the next ten years. It is not clear, however, why President Bush did not include the NIH in his effort to increase research funding. It may have appeared to the White House that the NIH, having just had its budget doubled, had enough money. Or perhaps the President felt he could only invest an additional $1.3 billion in research and, at around $28 billion in FY 2006, a 4 percent increase for the NIH would have claimed almost all the money available. Whatever the reason, Congress did not push back, and the NIH continued its slide, with serious repercussions throughout the U.S. biomedical research community.

President Bush's ACI was superseded by the America COMPETES Act of 2007.[205] This act had similar objectives to the ACI, with aggressive budget increases for several research agencies that fund physical sciences and engineering. The act was reauthorized in 2010, driven by the 2010 National Academies report *Rising Above the Gathering Storm, Revisited: Rapidly Approaching Category 5*, and was similar in spirit to the 2007 COMPETES Act, but with smaller budget increases.[206] Actual appropriations for FY 2013 fell far short of even the more modest levels authorized in the 2010 America COMPETES Act.

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203. "American Competitiveness Initiative," White House Archives, February 2, 2006, http://georgewbush-whitehouse.archives.gov/stateoftheunion/2006/aci/index.html.

204. Institute of Medicine et al., *Rising Above the Gathering Storm*.

205. *America COMPETES Act of* 2007.

206. Matt Hourihan, "Agency Budgets in the FIRST Act and America COMPETES," American Association for the Advancement of Science, March 12, 2014, http://www.aaas.org/news/agency-budgets-first-act-and-america-competes.

Appendix C: National and Federal Investments in Research, 1957–2012

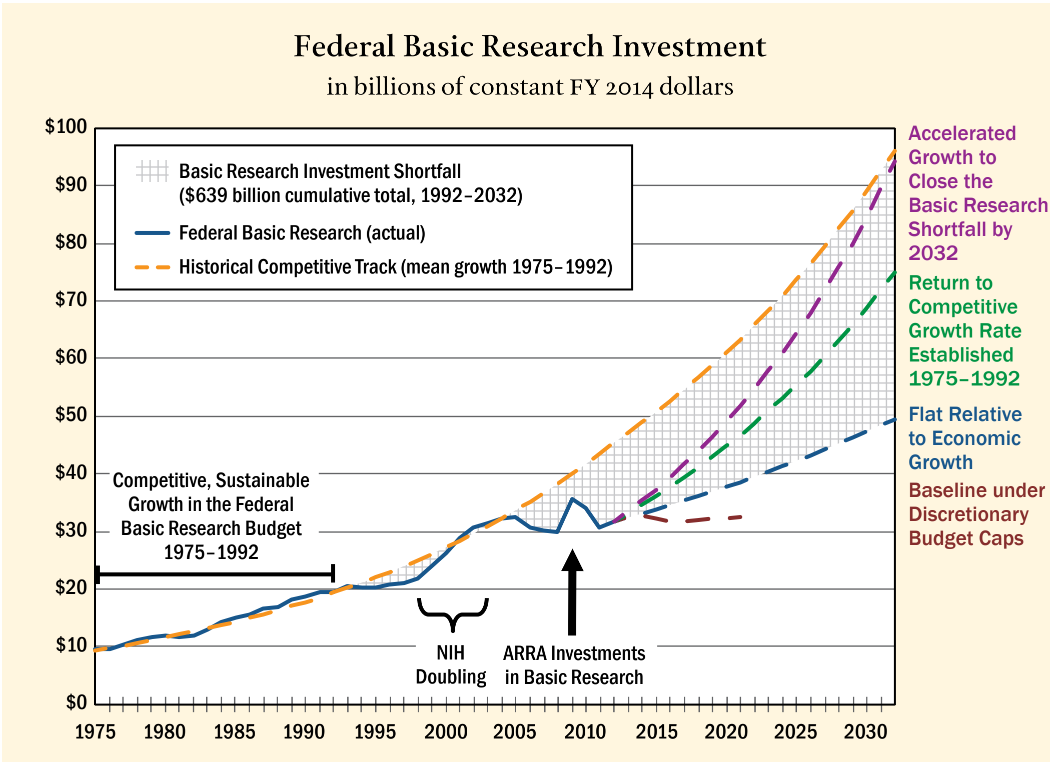

Figure 14

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.

Note: Orange trend line is a best fit (least squares regression) of federal obligations for basic research (constant 2014 dollars) between 1975 and 1992.

Source: Federal obligations for basic research from 1975 to 2012 are from 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 the 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, doi:10.1787/5kgondkjvfhf-en.

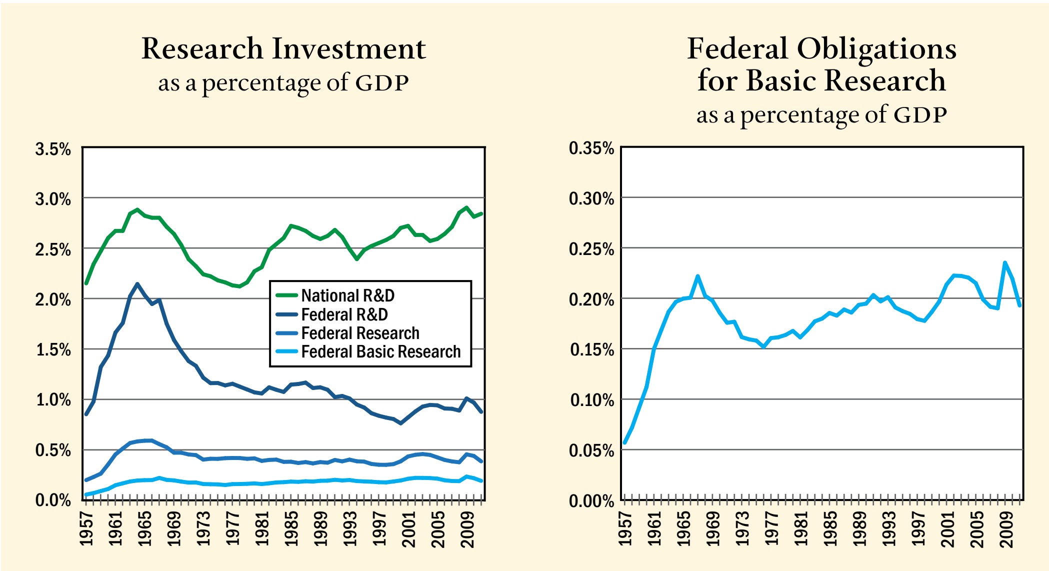

Figure 15

National R&D Expenditures and Federal Obligations for R&D, Research, and Basic Research, 1957 – 2012

Left panel: National R&D expenditures (green) and federal obligations for R&D (dark blue), research (blue), and basic research (light blue) are shown as a percentage of GDP from 1957 – 2012. Right: Federal obligations for basic research as a percentage of GDP.

Source: Federal obligations for R&D, research, and basic research 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." National expenditures on R&D are from the National Science Board, *National Patterns of R&D Data Update, 2011 – 2012* (Arlington, Va.: National Science Foundation, 2014), Table 6, "U.S. Research and Development Expenditures, by Source of Funds and Performing Sector: 1953 – 2012."

THIS REPORT IS AN URGENT CALL to recommit to one of our nation's most successful investments, which has stagnated: the investment in the people and research that have led to the amazing scientific and engineering discoveries underpinning U.S. world leadership. Failure to address our nation's widening "innovation deficit" will result in the squandering of the international economic and technological leadership that is so vital to our societal welfare. Industrial, government, and academic leaders must work together to implement the sound recommendations in this report.

– **Peter McPherson**, President, Association of Public and Land-grant Universities

THIS REPORT MAKES ABUNDANTLY CLEAR the threat our nation faces to its standing as the global leader in science and innovation. Even more importantly, it lays out three prescriptions for the future health of the U.S. science and engineering enterprise that reflect fiscal reality, emphasizing long-term strategic thinking and calling for the federal government, industry, and universities to take steps to renew their historical partnership. The wise recommendations in this report can help our nation close the innovation deficit; they should, and must, spark action.

– **Hunter R. Rawlings III**, President, Association of American Universities

AMERICAN BUSINESS HAS long supported a strong federal role in basic research, which is the foundation of the private-sector innovation that drives economic growth, but the United States is now falling behind. *Restoring the Foundation* explains in clear terms what this slippage means – not just for the U.S. economy but also for our nation's place as a world innovation leader – and offers solid recommendations for regaining our global research leadership. Policy-makers considering strategies for economic growth should make *Restoring the Foundation* part of their own basic research.

– **John Engler**, President, The Business Roundtable; former President and Chief Executive Officer, National Association of Manufacturers; former Governor of Michigan

THIS IMPORTANT REPORT makes a convincing case that the achievement of the American Dream depends on reviving the nation's historic reputation for leading the world in scientific and technological research. The Academy not only sets the goal for investment in new discoveries and the technologies to realize their great benefits, it also lays out a detailed set of policies that, if implemented, will increase the value of this research and reduce its costs. In this respect, this study is unique and especially deserving of careful consideration.

– **Lewis M. Branscomb**, Adjunct Professor, University of California, San Diego; Professor Emeritus of Public Policy and Corporate Management, Harvard University

MERCK STRONGLY SUPPORTS the American Academy's report and its recommendations to improve the health of the American science, engineering, and technology enterprise. We recognize that the best scientific discoveries often emerge from collaborating with other researchers and organizations inside and outside our laboratories. We endorse the implementation of the Academy's "prescriptions" for improved government, university, and industry collaboration as critical steps to ensuring U.S. leadership in global scientific discovery and innovation.

– **Kenneth Frazier**, Chairman of the Board, President, and Chief Executive Officer, Merck & Company, Inc.

AMERICAN ACADEMY OF ARTS & SCIENCES