**Testimony of**
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**Before the**
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**Committee on Commerce, Science, Transportation**
**U.S. Senate**

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**"Research & Innovation: Ensuring America's Economic and Strategic Leadership"**

Science has long been at the heart of the American experiment. "An investment in knowledge always pays the best interest," noted Benjamin Franklin, and the revolutionaries who founded our Nation and enshrined the promotion of "the progress of science and useful arts" in the Constitution. Since World War II, advancements in science and technology have driven 85% of our economic growth, underpinned our national security, and transformed nearly every aspect of Americans' daily lives. New technologies built on federally-funded discovery research have led to new businesses, revolutionized health care, and created the mobile, digital world.

Our preeminence has not happened by chance. Sustained, bipartisan commitment to investing in fundamental research has played a key role in establishing and maintaining our innovation enterprise. As we make the investments our country needs to compete in the 21st century global economy, we must renew our commitment to strengthening this key component of our national infrastructure and ensuring that we are not technologically surprised in key areas like quantum computing and artificial intelligence. Collectively, we must do this because the world has changed, and our country has changed. We no longer live in the world of Vannevar Bush, in which American S&E leadership was almost inevitable, or even on the edge of a gathering storm. Research is now a truly global enterprise, more connected, complex and nuanced than a "storm," with opportunities everywhere and humanity's collective knowledge growing exponentially. This is a brave new world, and while American preeminence is not assured, I think we should react with excitement, not fear. We are well positioned to compete, collaborate, and thrive.

The freewheeling creativity and entrepreneurial ethos that infuses our researchers is the "secret sauce" of America's scientific and engineering (S&E) enterprise. A wonderful example of this ethos can be found in the story of this year's Nobel Prize in Chemistry. After arriving in the US to take up a postdoctoral fellowship at Stanford University, Dr. Stanley Whittingham's research in fundamental chemistry focused on the phenomenon of intercalation in solid materials. His work led him to propose that these materials could be used as electrodes in powerful batteries. Using superconducting materials and lithium, he

invented the rechargeable lithium battery while working as a research scientist at Exxon, which was interested in developing alternatives to gasoline-powered vehicles during the oil crisis of the 1970s. Dr. Whittingham was granted the original patent on the concept for this type of battery, and his foundational research, developed further by his co-laureates, ultimately led to the invention of rechargeable lithium-ion batteries – which now power everything from industrial technologies to the mobile phones we all hold in our hands.

This story encapsulates many of the strengths of our nation's S&E ecosystem – support for fundamental science from both the federal government and the private sector, welcoming of talent from around the globe, and giving the best minds the freedom to explore new frontiers and see where discovery leads them. The freedom of inquiry enabled by federal support for fundamental research through NSF and other government agencies has led to surprising new knowledge that has advanced our nation in unexpected, unpredictable ways. As President Ronald Reagan noted, "The remarkable thing is that 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." The federal government is key to these endeavors, because it can make a strategic long-term commitment to creating new knowledge. History has shown that taking risks on creative researchers and bold ideas has paid off time and time again, with all sectors of our knowledge ecosystem – universities, government laboratories, industry – partnering to drive innovations.

So, this is our "ask" for this committee: **Be Fearless**. Let us not merely react based on anxieties about increased global competition, security threats, or current budget limitations. Instead, ask how we can grow our economy, lead the next era of science and engineering, remember the "can-do" attitude that defines America, and recommit to the partnerships among governments, universities, and private industries that has driven our success. Let us unleash our strengths – a spirit of exploration, of wonder, of discovery; coupled with a willingness to take risks and an emphasis on freedom and individual creativity – to ensure America's continued preeminence in research and innovation in the 21st century. *Because the best way to lead the future is to invent it.*

**U.S. Research and Innovation in the Global Context**

Since 2000, global research and development (R&D) investments have tripled, reflecting increased competition in knowledge-intensive industries and recognition of the crucial role R&D plays in addressing global health, security, and environmental challenges. NSB's forthcoming *Science & Engineering Indicators 2020* report confirms a trend that NSB has observed for several years: while the U.S. remains a leading player, other countries have seen the benefits of investing in research and education and are following our example.[1] The world of R&D performance, historically centered around the U.S., Western Europe, and Japan, has been shifting toward East and Southeast Asia.

While China is not the only story, it continues to exhibit a dramatic R&D growth trend. In 2018, the NSB issued a statement noting that China would likely surpass the U.S. in total R&D expenditures by the end of 2018. The most recent data, from 2017, show that while there was higher growth in U.S. business R&D than previously projected, the trend lines in Figure 1 suggest that China either has passed us already in R&D expenditures, or will by the end of 2019.

[1] National Science Board (2020). "Research and Development: U.S. Trends and International Comparisons," *Science & Engineering Indicators 2020*, forthcoming.

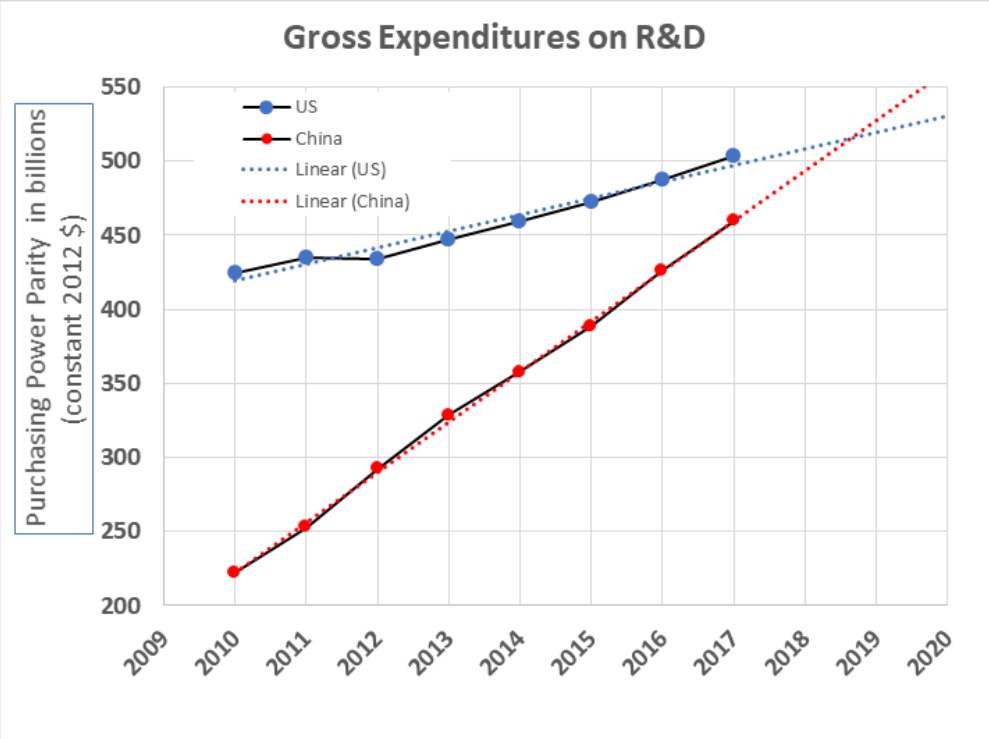


*Figure 1: Gross Expenditures on R&D for the U.S. and China*

Amid this dramatic growth in China's R&D investment, it is crucial to note that the U.S. maintains a significant advantage in *basic* research – which is the seed corn for our entire S&E enterprise. In 2017, the U.S. invested $92 billion in basic research; China comes in a distant second, investing $27 billion. While U.S. business sector investment in total R&D has recently grown faster than the federal government's investment, the lion's share of their investment has been on the applied and development side. In the U.S., 42% of *all* basic research is funded by the federal government, about half of which is performed at higher education institutions.

To produce results, R&D investments must be coupled with building a highly skilled, STEM-capable workforce, including everyone from associate's degree holders to PhDs. Today, we are seeing changes in S&E employment driven by international opportunities and competition, and by disproportionate growth in the number of jobs at all levels that require STEM skills. As of 2017, nearly 21 million workers with at least a four-year degree say that their job requires a "bachelor's level" of STEM expertise – and the vast majority of these workers (71%) are employed by the business sector, the cornerstone of the nation's economic competitiveness.

These numbers do not include the more than 17 million people who use S&E skills in their job but do not have a bachelor's degree. As highlighted in the NSB's new report, "*The Skilled Technical Workforce: Crafting America's Science and Engineering Enterprise*," these skilled technical jobs pay well, are found across the U.S., and are vital to the health of local economies as diverse as Detroit, Michigan; Florence, South Carolina; and Baton Rouge, Louisiana.[2] These individuals, who account for more than 50% of all workers in many of America's advanced industries, bring digital, math, and coding skills to work as auto

[2] National Science Board (2019). "The Skilled Technical Workforce: Crafting America's Science & Engineering Enterprise," NSB-2019-23.

mechanics, health care technicians, electricians, welders, computer systems analysts and administrators, and operators of "smart" infrastructure. Skilled technical workers are also critical to our nation's S&E infrastructure, for instance in building and maintaining the miles of high vacuum pipeline and two-story banks of air filters that make the Laser Interferometer Gravitational-Wave Observatory (LIGO) work.

Foreign-born individuals have long been major contributors to our S&E enterprise. As of 2017, over 40% of our doctoral-level S&E workforce was foreign-born[3], and over half of the doctoral degrees in engineering, computer sciences, and economics were earned by international students on temporary visas.[4] Highly skilled S&E workers have become increasingly mobile and nations have adapted their immigration policies to make it easier for these valued workers to relocate and work in their countries. At the same time, the U.S. share of worldwide internationally mobile students has declined slightly, even as the number of these students has risen dramatically worldwide. These changes indicate an accelerating competition for globally mobile talent. As more countries offer their students reasons to stay in their own country for their education or to return home after earning a degree, the U.S. could face a shortage in a critical segment of its workforce.

**Looking to the Future**

Why is U.S. preeminence in S&T so important? From quantum computing to artificial intelligence to the data revolution, scientific advancements come with both opportunities and risks. To mitigate those risks in an increasingly competitive world, it is essential that we stay at the forefront of science and cutting-edge research and maintain a strong economy. The past has shown that investment in basic research now will give us the keys to meeting the security, health, and economic challenges of the future – challenges we know will arise but whose nature we cannot predict.

We know that China and other nations are actively working to lead in research areas that hold enormous promise for revolutionizing our world, such as artificial intelligence (AI) and quantum computing. The White House and Congress are stepping up to meet this challenge, with increased focus and investment in key areas of S&E research and development. With sustained federal investments, the Administration is advancing U.S. leadership in Industries of the Future: AI, quantum information sciences, 5G/advanced communications, synthetic biology, and advanced manufacturing R&D. The NSB applauds these efforts – it is wonderful to see the influx of national attention and both public and private sector investment in these areas, and NSF will continue to play a key role in addressing fundamental questions in these fields as we go forward.

It is worth noting that many of these research areas are ripe for an explosion of public and private investment in part *because* NSF supported early-stage research in these fields years ago. So in addition to furthering the development of research fields that are cutting-edge and now widely recognized as important, at its core, a central mission of NSF is to ask: what is the *next* big thing? NSF is the only agency that supports basic research in *and among* all areas of science. Identifying the most promising, creative ideas of America's research community, through rigorous peer review, is what will lead to the transformative discoveries that will shape our world decades from now. To continue our success, I advocate three things.

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[3] National Science Board (2019). "Science & Engineering Labor Force," *Science & Engineering Indicators 2020*. NSB-2019-8.
[4] National Science Board (2019). "Higher Education in Science & Engineering," *Science & Engineering Indicators 2020*. NSB-2019-7.

### 1- Continued robust federal funding for basic research

First, the nation needs robust, sustained federal funding for research. The trends of other countries investing heavily in R&D are expected to continue as they recognize that such investments translate into economic growth and create jobs. Congress recognized this and responded in FY 2019; and we thank you also for the strong, bipartisan support shown for NSF in the initial FY 2020 Appropriations bills But even with these increases, government spending on R&D is 0.7% of GDP, as compared to 1.69% in 1960. Since 2000, as worldwide investments in R&D have tripled, NSF's funding rate for grant proposals has fallen from 33% (total submitted proposals: 29,508) in 2000 to 21% (total submitted proposals 40,678) in 2017, leaving $1.6 billion in great proposals unfunded.[5] When that happens, the researcher may leave the country to pursue his/her work, submits the proposal elsewhere, perhaps to one of our international competitors, or the idea dies in the intellectual dustbin of unfulfilled promise, as the researcher drops the line of inquiry, or – worse – leaves S&E for another career. We need to maintain the trajectory on which your recent generous investments have placed NSF.

Funding without direction is akin to an airplane with no compass. As we seek to "be the best version of ourselves," we need to formulate a strategy that considers everything from national needs to competitive advantages to technological opportunities. We need an enduring commitment to S&E leadership. An effective plan, built on a holistic evaluation of our national research portfolio, and a recognition that the best ideas come from researchers, would help us match our strategic priorities with our investments. If we are to continue to champion our "secret sauce" of freewheeling creativity and entrepreneurial ethos, our vision of the future cannot be limited to competing with other countries in the current areas of global importance. To pursue the next "big thing," our brightest minds will need the time, space, and resources to scout the path to new frontiers.

NSF has long sought a balanced portfolio, one that recognizes and embraces the knowledge that transformational discoveries often grow out of repeated "dead-ends" and small steps. Our portfolio balances large, long-term investments like LIGO with awards to individual investigators and small teams that can nimbly pursue innovative, out-of-the-box research. In recognition of the growing complexity and cost of some research, NSF's portfolio also includes collaborations across disciplines, institutions, and research sectors, areas ripe for transformative discovery.

In anticipating what's next for our national ecosystem, it is important to recognize the interdependent roles in our current one. A basic research agency like NSF has significant differences in scope and time horizons from private business and mission agencies. Partnerships among and between the federal government and universities, between universities and the private sector, and those with other non-profits have led to a system in which the federal government funds a majority of fundamental research, universities perform a majority of it, and industry funds and performs a majority of applied and developmental work. Public funding of curiosity-driven research is a sustained commitment over a long time horizon, and a competitive advantage for the United States. These investments set the table for directed research of the mission agencies and the private sector. Indeed, Figure 2 shows that the percentage of U.S. patents derived from government-funded research is near its all-time high.[6]

[5] Report to the National Science Board on NSF's Merit Review Process, Fiscal Year 2017, NSB-2019-15.
[6] Fleming et al. (2019). "Government-funded research increasingly fuels innovation," *Science*, 364(6446) 1139-1141.

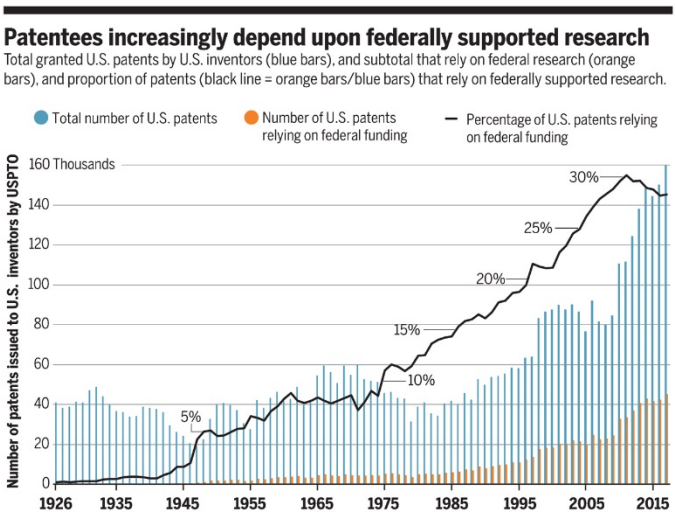


*Figure 2: Increased dependence of U.S. patent on federal R&D*

*From: Fleming et al. (2019). "Government-funded research increasingly fuels innovation," Science, 364(6446) 1139-1141.*

## 2- Fostering America's talent

More countries than ever are competing for the best minds, and these individuals have choices today that did not exist as recently as 20 years ago in selecting a place to study, perform research, and innovate. Industry and the federal government report that they are unable to find enough workers at all levels with enough STEM knowledge and skills. These reports are especially concerning in the national security arena, where employees must be U.S. citizens. For example, the National Security Agency has reported significant levels of attrition among personnel whose jobs require substantial STEM knowledge.[7]

Our ability to discover, invent, and innovate *relies* on our ability to train our own people while continuing to attract and retain the best and brightest from around the world. Recruiting the next generation will mean dispensing with outmoded stereotypes of scientists and engineers. As ideas live in people – not papers – this is a striking opportunity for our country. Our nation's diversity of perspective and experience can be a boon to creativity; our culture of risk-taking and entrepreneurship is an asset for turning discoveries into innovations; and our values of individual freedom – including the freedom to fail – openness and collaboration are natural accelerants of basic research.

The NSF Act directed the Foundation to "strengthen research and education in the sciences and engineering…throughout the United States, and to avoid undue concentration of such research and education." The Board strongly agrees with this charge – no zip code or demographic should be unable to participate in the S&E economy, and we need *all* of our domestic talent if we want to compete in this era of globalized discovery. We must use the abilities and creativity of all our citizens. To do so, we must do more to diversify our STEM-capable workforce, particularly as, according to the Census Bureau, by 2042 our country will be a majority-minority nation.

NSB believes that for our Nation to continue to thrive and lead in the industries of the future we can no longer rely on a relatively small and distinct "STEM workforce." Congress, the Administration, business leaders, educators, and other decision-makers must work together to ensure that Americans have the

[7] Nakashima, Ellen & Gregg, Aaron. "NSA's top talent is leaving because of low pay, slumping morale and unpopular reorganization." *Washington Post*, Jan. 2, 2018.

STEM knowledge and skills to thrive, leveraging the hard work, creativity, and ingenuity of women and men of all ages, education levels, and backgrounds.[8] We must improve STEM education here in the U.S. by giving everyone the opportunity for hands-on learning starting at an early age, for example. We need to remember that education is a public good, and that public universities and colleges have a special role to play in providing access to high quality STEM education to students in every state. We must provide our citizens with the problem-solving skills needed for the lifelong learning that is now required to adapt and thrive in a rapidly changing job market, one often driven by advances in S&E. We need scientists in every region of the country searching for cures, engineers building stronger bridges, factory workers making our cars safer, technicians keeping our labs and hospitals operating, and farmers producing healthier crops using fewer resources.

Even as we work to build our domestic STEM-capable workforce at all levels, including the skilled technical workforce, there is another component to maintaining our preeminence in S&E. It is critical that we continue, through clear and consistent policies, to welcome curious, creative, and ambitious researchers from overseas. This does not mean being naïve – other nations are actively courting this globally mobile talent, sometimes aggressively enough to violate U.S. government policies. Rather it means welcoming those who embrace our values.

### 3- Embracing and promulgating our values

In the belief that the pursuit of knowledge is a universal global enterprise, best undertaken through an open exchange of ideas and sharing of outcomes, with limited national security exceptions, the U.S. must avoid the temptation to engage in a head-to-head competition with those who choose to conduct their fundamental science and engineering enterprise with less transparency. Instead, the U.S. should reaffirm its unambiguous commitment to the highest ethical and technical conduct of its research, leading the way in open worldwide collaborations, open publication, and archiving data for public use. The U.S. should work with those who share our values, remaining confident in its conviction that behavior as a model citizen in the science and engineering community will serve as an example for others to emulate, as well as maintaining the U.S. as the destination of choice for the world's best minds. Through principled leadership in the exercise of science and engineering research, the U.S. will retain its seat at the table of like-minded nations. The partnerships and research collaborations that flourish in an environment of shared values will provide an incubator for an unlimited variety of scientific and engineering discoveries. These discoveries, in turn, could generate new innovative solutions to global problems and/or reveal heretofore unknown secrets about our universe.

This is not a naïve vision of utopia. There are sensitive areas of research in which national security considerations must prevail. National security and economic espionage conducted or supported by foreign entities must be vigorously challenged. U.S. universities and colleges must help promote scientific openness and integrity and safeguard information that impacts national security and economic competitiveness, including rigorously adhering to conflict of interest and conflict of commitment policies. But, as stated in President Reagan's NSDD-189, "The strength of American science requires a research environment conducive to creativity, an environment in which the free exchange of ideas is a vital component." National Security Advisor Condoleezza Rice reiterated this U.S. commitment in 2001, stating, "The key to maintaining U.S. technological preeminence is to encourage open and collaborative basic research. The linkage between the free exchange of ideas and scientific innovation, prosperity, and

[8] National Science Board (2018). "Our Nation's Future Competitiveness Relies on Building a STEM-Capable U.S. Workforce," NSB-2018-7.

U.S. national security is undeniable." Consistent with these pronouncements, distinctions must be made between the truly critical secrets and the inconvenient losses that can occur in an open society. If the U.S. continues to conduct its S&E enterprise consistent with the principled traditions that have yielded the success of the past 75 years, the benefits it realizes from nurturing a global community of similarly principled partners will far outweigh the losses it may suffer as a result of the openness it champions.

**Conclusion**

Fifty-nine years ago, President John F. Kennedy set America on a path to the Moon. In 2019, as we celebrate the 50th anniversary of humanity's first steps on that new world, we find ourselves once again in "an hour of change and challenge." Competition and excitement arise from science and technological advances everywhere, in every field, in research and industry and academia and business, and from many other nations, who are seeing their chance to rise. Healthy competition provides benefits to all of humanity – science, and particularly fundamental research conducted in a transparent and open fashion, is not a zero-sum game. New knowledge benefits everyone. If the U.S. wants to invent the future, then we must up our own game, emphasizing freedom, individuality, creativity, and risk-taking, building on a foundation of community that is diffuse and networked, open and transparent.

Our national commitment to winning the race to the Moon, and our belief that we could do anything we put our minds to, spurred creative collaboration and competition that resulted in scientific and technological advances that have benefited every one of us, far beyond the original goal. Today, let us be inspired to once again dream boldly and take risks in the pursuit of fundamental knowledge and innovation. Maintaining our global leadership will require increased efforts from government and industry, working in partnership with our world-leading public and private universities. Together, we can pursue grand visions, enable revolutionary ideas, and see what unexpected advances may emerge from asking fundamental scientific questions.

As I conclude, I return to the story of Dr. Whittingham, now at the State University of New York, where his continuing work to improve battery technology has been supported by NSF for over 30 years. He discovered a fundamental chemical property of specific solid materials, and *then* saw the potential applications of his discovery – taking him down a new, unexpected path that led to an invention that changed our world. Stories like this are why we need to attract and fund the best *people,* as well as the best ideas. For the US to maintain preeminence in S&E, for us to invent the future, we need to develop and attract the best minds. Then we must give them the time and space – and resources – to explore, to not be sure exactly what they might find, or why it might be useful; but being sure in the knowledge that discovery will ultimately reap huge, unexpected benefits for humanity. We know this because we have seen this story of unleashed creativity play out, over and over again. It is what has brought us the technology-driven world we live in today – and it is what will bring us the innovations that will shape our tomorrows.

**If we are bold. If we are fearless.** If we are true to our heritage as a nation of people who were not circumscribed by the boundaries of others, but who instead looked over the horizon and asked: What's out there? *What's next?*