Written Testimony of Dr. Kelvin K. Droegemeier
Vice President for Research
Regents' Professor of Meteorology and Weathernews Chair Emeritus
University of Oklahoma
Vice Chairman of the National Science Board

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I thank Chairman Rockefeller, Ranking Member Thune, and Members of the Committee for the privilege of testifying on the important role played by science and engineering research and education in our Nation's competitiveness. My name is Kelvin Droegemeier and I am Vice President for Research, Regents' Professor of Meteorology, and Weathernews Chair Emeritus at the University of Oklahoma. I also am a member of the National Science Board (NSB, Board), which establishes policy for the National Science Foundation (NSF) and serves as an independent body of advisors to both the President and Congress on matters related to science and engineering research and education. I am testifying today in my role as NSB Vice Chairman.

On behalf of the Board, I thank the Members of this committee for their long-standing commitment to fostering national prosperity, economic security, quality education, and international competitiveness through support for basic research in science, technology, engineering and mathematics (STEM).

An important component of this commitment has been the America COMPETES Act.

Enacted in 2007 and reauthorized in 2010, the Act provided a framework for catalyzing research in areas of national priority and for coordinating Federal STEM education efforts. At NSF, the Act enabled continued investment in our Nation's scientific infrastructure, innovation in STEM education, and development of a portfolio of research investments that respond to current national challenges while laying the foundation for a robust scientific and technological enterprise into the mid-21st century. It also promoted excellence in scholarship via training in the responsible conduct of research, and the mentoring of post-doctoral researchers.

1. NSF and the Importance of Basic Research

The idea for NSF arose in the wake of the Second World War. President Roosevelt, recognizing that wartime cooperation between the Federal Government and scientific community had contributed to the U.S. victory, asked his *de facto* science advisor, engineer Dr. Vannevar Bush, to develop a report describing how the Government could promote scientific progress in the postwar period. That report, *Science – The Endless Frontier*, called for the creation of NSF and stressed the *essential role of the Federal Government* in cultivating the Nation's "scientific talent" and in *funding basic research*.

Basic research, which represents structured inquiry motivated by the innate human desire to understand the fundamental behavior of the world in which we live, is the DNA from which new innovations and technologies arise to fuel our Nation's economy. That DNA, representing thousands of discoveries across all disciplines, can be assembled, refined, set aside for a time until other advances call upon it, and re-used in an almost infinite number of ways to produce outcomes that have profoundly positive benefits for society. Bush argued that investments in basic research were essential to American national security and competitiveness, and that same wise notion was the foundation of the COMPETES Act and is the principal reason NSF is featured prominently within it.

NSF funds the highest quality projects having the potential to advance, if not transform, the frontiers of knowledge and advance societal goals. Two criteria, "Intellectual Merit" and "Broader Impacts," shape the NSF merit review process, which is viewed as the gold standard worldwide. NSB recently re-examined these criteria to ensure that NSF maximizes the public's return on investment.

2. The U.S. Research and Innovation Ecosystem and NSF's Role in it

Basic research, applied research, and development in the U.S. are dominated by development activities – 78 percent of which are funded by the private sector. Private industry also is the largest source of funding for applied research. In this context, the Federal Government, and NSF in particular, play a critical, complementary role by supporting *basic research*, the majority of which is performed at our Nation's colleges and universities. Private industry relies on the new knowledge created by basic research to develop new and innovative products and services.

Because the returns on investments in basic research are unpredictable and may take years, if not decades, to materialize, the private sector understandably invests relatively little money in it. Consequently, as noted by Vannevar Bush, the Federal Government has an *essential role* in supporting basic research. NSF's role in particular is *unique* because it is the only agency that funds basic research and education across all STEM disciplines (excluding clinical medical research) and (presently) at all levels of STEM education.

3. Samples of Economic and Societal Returns on Investment in Basic Research

For over 60 years, with the support of Congress, NSF has been funding basic research, enabling our Nation to become the undisputed world leader in science and technology. As noted previously, linking basic research outcomes to innovated products and services can be difficult because the path from the former to the latter is often indistinct, sometimes evolving over long periods of time and integrating elements from multiple disciplines and technologies. However, examples large and small abound and are important for demonstrating the value of basic research to, and the thoughtful investment of tax dollars toward achieving, national competitiveness. A few are provided below.

- NSF-funded mathematicians have re-applied algorithms that predict earthquake aftershocks and created a crime prediction model. After police implemented the crime prediction model in Los Angeles' Foothill precinct (300,000 residents), **crime decreased 12 percent** relative to surrounding areas.

- Almost 20,000 kidney transplants are conducted each year in the U.S. Based on their knowledge of game theory and market dynamics, NSF-funded economists developed an algorithm that facilitates kidney matching for patients who have willing but biologically incompatible donors. The **number of transplants** performed through paired exchanges has risen dramatically: **from 2 in 2000 to 443 in 2012**.

- Coronary artery disease, the major cause of heart attacks, annually afflicts more than 700,000 Americans and costs the Nation nearly $110 billion to treat annually. NSF-funded researchers developed mathematical tools to better understand and control interactions between arterial walls and blood flow. Subsequently, scientists improved stents to help open narrowed arteries and later formed a biotechnology company that is publicly traded on NASDAQ and currently has a value of nearly **$950 million.**

- As part of its start-up funding, Qualcomm received a Small Business Innovation Research award from NSF. Over 21,000 employees and 170 locations later, this company has forever changed the face of digital wireless telecommunications products and services. Qualcomm is now worth more than **$100 billion.**

One often overlooked aspect of basic research is that it helps our Nation be prepared for the unexpected. When confronted with entirely new challenges, time often does not exist to conduct the thoughtful, intensive studies associated with basic research. Consequently, having research outcomes in hand is essential. Nowhere is this more evident than in current and rapidly evolving national security challenges, where results from previous basic research in image processing, electro-chemical sensing, and data mining have led to the rapid creation of field-deployed technologies for enhancing security in airports, better ensuring the safety of the war fighter, and fighting new generation cyber attacks.

These and thousands of other examples – which show how basic research in science and engineering leads to practical benefits via innovation – directly impact the ability of the U.S. to be competitive in a global society: competitive economically, competitive in education, competitive technologically, and also secure. Consequently, by virtue of its unique mission, NSF funding of basic research continues to be central to U.S. competitiveness.

Another important and easily overlooked aspect of basic research is the talent pool needed to perform it in our Nation's colleges and universities, and to innovate with its outcomes in the private sector. STEM education is the *sine qua non* for this workforce and is a foundational component of NSF's portfolio. Without it, and without efforts to ensure a diverse workforce that draws upon and reflects the increasingly diverse structure of our Nation, the competitiveness of the U.S. will suffer immeasurably.

4. Toward a Globally Competitive Nation

What does it mean to be competitive? In sports, business, and the military, one cannot *win* unless one is competitive. The U.S. must be globally competitive in order to be a world leader – in research, technology, advanced manufacturing, educational attainment, private sector innovation, public-private partnerships, economic prosperity, and quality of life. Unfortunately, numerous metrics and studies show that the U.S. is rapidly losing its competitiveness.

According to a 2012 report[i] by the U.S. Department of Commerce, the strengthening economies of several countries around the world are posing a competitive challenge for the U.S. The ability of the U.S. to create jobs has slipped, and it has made little progress in competitiveness during the past 2 decades, now ranking fourth in the world in innovation-based competitiveness. The preparation of U.S. students in math and science is notably problematic, with 17 Organisation for Economic Co-operation and Development (OECD) countries ranked above the U.S. Numerous equally sobering statistics exist and are readily available. NSF is vitally important in restoring U.S. competitiveness by building competitive capacity in many ways.

First, as noted previously and via a wide array of programs across all disciplines, NSF funds basic research at the frontiers of discovery and thus creates new knowledge – the DNA of innovation. Many of NSF's activities focus on areas of national priority and thus lie at the heart of national competitiveness. These include, at the present time, advanced manufacturing, robotics and cyber-physical systems, interdisciplinary research to enrich our understanding of the brain's neural networks, nanotechnology, STEM education, global change research, and cybersecurity research and development.

Second, NSF funds the construction of modern research infrastructure that is critical to maintaining U.S. technological competitiveness. Through its Major Research Equipment and Facilities Construction (MREFC) account, NSF provides our Nation's scientists and engineers with the powerful, large, complex tools necessary to perform world-class research. This includes – but is not limited to – telescopes, supercomputing facilities, ships, airplanes, and large arrays of observing systems for long-term sampling of the planet below ground, at the surface and in the atmosphere. Other programs, such as Major Research Instrumentation (MRI), provide funding to colleges and universities to both develop and acquire large pieces of equipment for research and education, with the responsibility for long-term sustainability borne by the receiving institution.

Third, NSF facilitates the education and training of the next generation of scientists and engineers (graduate and undergraduate students as well as post-doctoral researchers) by funding grants to support their research and training. Flagship programs such as the NSF Graduate Research Fellowship, which has produced several Nobel Laureates over the past 6 decades, are seminal to U.S. competitiveness and STEM workforce development. The longstanding NSF CAREER program, which funds early-career faculty, is critical for ensuring that the most outstanding new academic researchers get off to a strong start and begin making seminal contributions as soon as possible.

Fourth, NSF supports numerous programs to broaden the participation of traditionally underrepresented populations in STEM fields. This is an extremely important challenge for U.S. competitiveness in light of rapidly shifting national demographics, as well as the substantial intellectual talent that goes untapped when underrepresented individuals either leave STEM fields or fail to select them to begin with. Although progress is being made, it is far slower than needed for the U.S. to amass a STEM talent pool to ensure future competitiveness.

Fifth, NSF has undertaken efforts recently in partnership with the private sector, via its Innovation Corps (I-Corps) program, to play a direct role in the innovation process. Specifically, I-Corps is a set of activities and programs that prepare scientists and engineers to extend their focus beyond the laboratory and broadens the impact of select, NSF-funded, basic-research projects. Although knowledge gained from NSF-supported basic research frequently advances a particular field of science or engineering, some results also show immediate potential for broader applicability and impact in the commercial world. Such results may be translated through I-Corps into technologies with near-term benefits for the economy and society. Combining experience and guidance from established entrepreneurs with a targeted curriculum, I-Corps teaches grantees to identify valuable product opportunities that can emerge from academic research, and offers entrepreneurship training to student participants.

And finally, NSF's Small Business Innovation Research (SBIR) program, as another example, provides seed money for high risk, high reward private sector ventures. NSF recently conferred an SBIR award that has the potential to lead to widespread recycling of the wastewater produced in the process of natural gas extraction known as "fracking."

5. The Experimental Program to Stimulate Competitive Research (EPSCoR): A National Role Model for Capacity-Building and Enhancing Competitiveness

NSF is mandated by statute to ensure that all geographic regions in the U.S. contribute to science and engineering research and education via NSF support, and as a consequence play a meaningful role in U.S. competitiveness. A program foundational to achieving this goal is the Experimental Program to Stimulate Competitive Research (EPSCoR), which provides *research capacity-building funding*, based upon competitively-reviewed proposals, to states (formally known as jurisdictions) which historically have received comparatively small percentages of NSF support. At the present time, 31 jurisdictions are eligible for NSF support, and other agencies, including the National Aeronautics and Space Administration (NASA) and Department of Energy (DOE), have EPSCoR programs.

The current NSF budget for EPSCoR is approximately $160 million per year and is directed to a variety of programs designed specifically to build research capacity. The flagship program, known as Research Infrastructure Improvement (RII, Track-1), provides up to $20 million for 5 years to support areas of *strategic research importance* for jurisdictions based upon their state science and technology plans, most commonly in alignment with national research priorities. Multi-jurisdictional activities are becoming more common as a means for leveraging capability for addressing larger, more complex challenges. Additional leveraging occurs via mandated cost sharing from the jurisdictions themselves.

Since the program's inception in 1980, competitiveness of EPSCoR jurisdictions (which entered the program in four cohorts) has increased by as much as 41 percent. Topics addressed range from bioinformatics and climate adaptation to nanotechnology and STEM education. EPSCoR funding also builds capacity in cyberinfrastructure in ways strategically aligned with national research and education priorities.

In addition to building capacity for basic research, EPSCoR plays an important role in economic development. As one of many examples, in my own state of Oklahoma, EPSCoR funding helped support one of the first NSF Science and Technology Centers in 1989, which I directed at the University of Oklahoma. This center pioneered a new science of computer-based prediction of thunderstorms, leading to the founding of a private weather technology company that now employs more than 80 people. Outcomes from this research are being transitioned into operations within the U.S. National Weather Service and hold promise for increasing the lead time for tornado warnings from 15 minutes to over an hour.

Additionally in Oklahoma, nanotechnology research funded by NSF EPSCoR played a role in the creation of a private engineering company that established the national standard (National Institute for Standards and Technology – NIST) for purity of single-walled carbon nanotubes – an essential element in hundreds of products. More than 20 nanotechnology companies are now located in Oklahoma, catalyzed in part by the EPSCoR investment. Additionally, more than 12,000 K-12 students, 1,800 teachers, 7,000 university students, 2,000 university faculty, and 59 businesses in Oklahoma have been served directly by EPSCoR education and outreach programs during the past five years.

Similar examples can be found for other EPSCoR jurisdictions. In Montana, substantial growth in academic research programs is credited with increasing the number of high technology companies from 17 to 175. In Idaho, it is estimated that every Federal dollar invested in EPSCoR programs has yielded $18 to the local economy. In Louisiana, nearly 22% of students supported by EPSCoR have come from underrepresented groups. And in Wyoming, research investments by EPSCoR helped position the state to host a major supercomputing center for the National Center for Atmospheric Research, which is catalyzing new research, education and technology development activities across the entire region.

6. Summary and Closing Thoughts

More than 60 years after its establishment, NSF remains a crucial component in the engine of U.S. innovation, competitiveness, and security. The agency's work is more vital than ever because science now has bearing on almost every aspect of our lives, from national security and global economic competitiveness to our health, quality of life and future workforce needs. NSF-sponsored research continues to open new frontiers by balancing NSF's longstanding "grass roots" vision of science with an agency-wide commitment to fund research addressing national priorities.

NSF's work in STEM education remains vital to ensuring that America's students, workers, and scientists remain competitive in the globally connected world. Although the context in which NSF operates today differs markedly from the post-World War II and Cold War worlds out of which it arose, the necessity of Government support for basic scientific research, for research infrastructure, and for educating the next generation of researchers remains as true today as in 1950. Then as now, basic research catalyzes the scientific and technological ecosystem. Then, as now, neither industry nor academia alone could make sufficient investments in basic science to sustain national competitiveness and security.

This is a difficult time for Federal budgets and for individuals in the academic, nonprofit and public sectors who rely on Federal support. Investments in science and technology compete with a host of other legitimate funding priorities. As other countries emulate our success by building their innovation infrastructures, we must be vigilant in sustaining our own innovative capacity. NSF remains committed to making the hard decisions needed to ensure that its portfolio obtains the greatest return on investment and maximizes the benefits of taxpayer support.

On behalf of the National Science Board, I thank you for your support of the National Science Foundation. We look forward to continuing our productive working relationship with you in service to the Nation.

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[i] U.S. Department of Commerce, 2012: The Competitiveness and Innovation Capacity of the United States. Available at http://www.commerce.gov/sites/default/files/documents/2012/january/competes_010511_0.pdf