The Role of the National Science Foundation in the Innovation Ecosystem

Overview

America's prosperity since World War II has originated in part from its ability to capitalize on ground-breaking discoveries from science and engineering research (Mansfield 1990, Tassey 2009). Simultaneously, a knowledgeable U.S. workforce has creatively translated discoveries from fundamental research into engines of innovation and has maintained the country's global leadership in crucial areas of technology. Such valuable discoveries and capable workers would not have been possible without substantial, sustained investment in science and engineering research and education.

During this same period, the National Science Foundation (NSF) has supported fundamental research in science and engineering[1] and the education of the science and engineering workforce. Discoveries made with funding from NSF have led to revolutionary technological advances and wholly new industries.[2]

America's past achievements benefitted from sustained investment in research and education and from steady access to capital and other resources. However, recent evidence indicates that the nation's technological advantage is shrinking for a variety of reasons (Atkinson and Wial 2008). If the United States is to maintain its edge in the future, how must strategies for promoting innovation in science and engineering change?

This informational white paper outlines a strategy by which NSF, particularly through its Directorate for Engineering, can use its experience, expertise, programs, and resources to facilitate and accelerate the translation of useful discoveries into industrial products, processes, and services. This approach builds upon NSF's strengths and is consistent with the President's Strategy for American Innovation (Executive Office of the President 2009).

From Discovery to Innovation

The process of innovation—the introduction of new or significantly improved products (goods or services), processes, organizational methods, and marketing methods in internal business practices or the marketplace[3] (NSF 2010a)—is complex and has been conceptualized in different ways. Technological innovation is a subset of innovation that draws heavily on the

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[1] NSF's annual budget represents about 20 percent of the total federal budget for basic research conducted at U.S. colleges and universities, and this share increases to about 60 percent when medical research supported by the National Institutes of Health is excluded. In many fields NSF is the primary source of federal academic support. http://www.nsf.gov/statistics/fedfunds/

[2] See, for example, the NSF document *Sensational Sixty*, a list of 60 NSF-funded inventions, innovations, and discoveries that have become commonplace. http://www.nsf.gov/about/history/sensational60.pdf.

[3] Many definitions of innovation have been published in the literature. The one above is taken from National Science Board's *Science and Engineering Indicators* and treats innovation to be related to the conversion of ideas into useful products and services. See Stone, Rose, Lal, and Shipp (2008) for a review of definitions.

scientific and engineering knowledge pool to create value for society through translational research; it is often depicted as an iterative process from basic science and engineering research at the start to production and marketing at the end (Figure 1).

Translational research—research that moves an idea past the basic discovery stage towards and through proof-of concept—can take many forms but is often characterized by the following features:

- It leads to technology platforms and often takes the form of engineered systems.
- It requires the integration of multiple disciplines.
- It is developed in collaboration with industry or other practitioners.

Translational research may involve prototyping, proof-of-concept tests, or scale-up and implementation (NSF 2010b). Ideally, translational research is integrated with commercial functions such as market, finance, manufacturing, legal, labor, and other contributors, to realize the potential of the innovation.

Moving from an idea or discovery to a product, process, or service on the market involves different contributors and requires resources from various sources. The funding and knowledge gap that exists between these two ends, known colloquially as the "valley of death," prevents many promising discoveries from reaching the commercialization stage (Auerswald and Branscomb 2003).

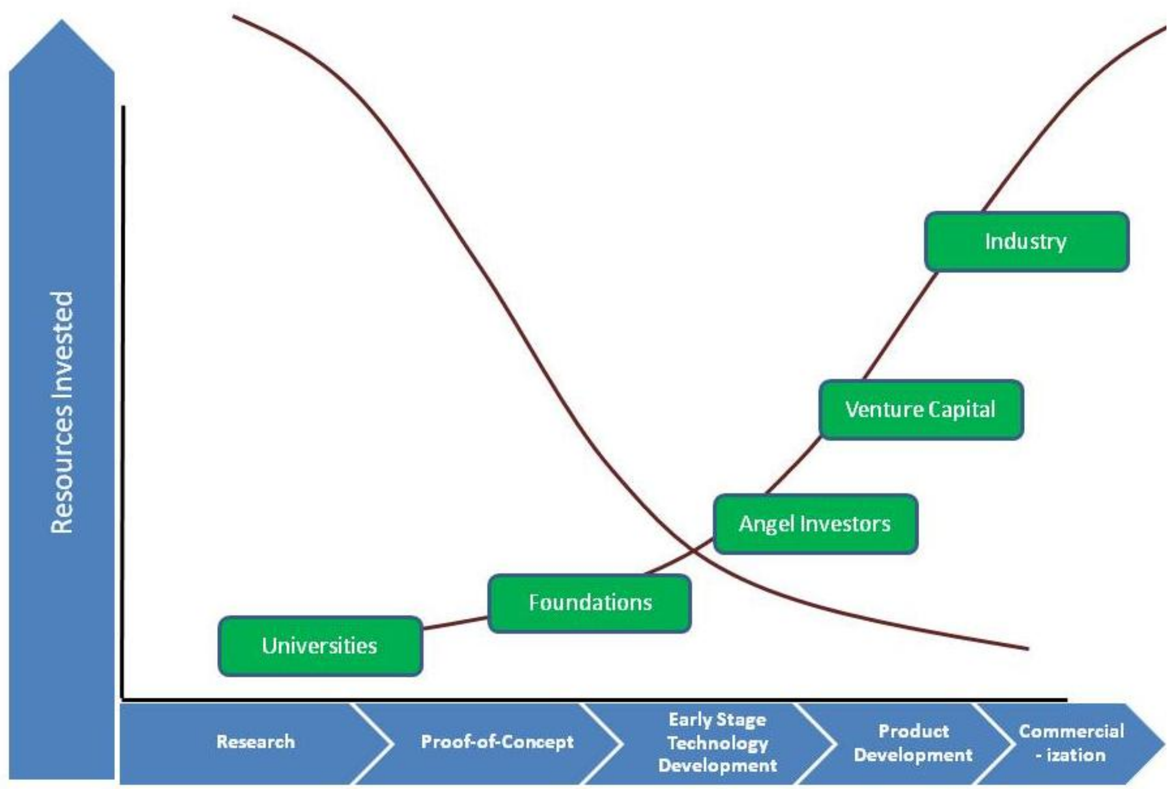

Figure 1: The linear innovation model and the "valley of death" in funding

The linear model is an oversimplification of the innovation process, and it misses many nuances involved in the non-linear, real-life process. One nuance that is typically not expressed through the linear model is that basic research—a building block for innovation—can be instigated by different motivations (Figure 2). A scientist or engineer may be interested in fundamental understanding of a phenomenon, and not take into consideration the ultimate end-use of their research (referred to as Bohr's Quadrant in Figure 2 below). Conversely, a scientist or engineer may be well aware of challenges to existing systems or industry needs, and may be motivated to undertake fundamental research that could potentially provide a breakthrough in those areas (referred to as Pasteur's Quadrant).[4] Discoveries from research in Pasteur's Quadrant are often especially suitable for translation into innovations.

Quest for Fundamental Understanding?	Considerations of Use? No	Considerations of Use? Yes
Yes	Pure Basic Research (Bohr)	Use-Inspired Basic Research (Pasteur)
No		Pure Applied Research (Edison)

Figure 2: Description of Research.
Source: Adapted from Stokes (1997)

Through its core activities in science and engineering, NSF has long supported research in both Bohr's and Pasteur's Quadrants. As the Directorate for Engineering Advisory Committee has stated, "traditional programs at NSF have centered on the first stage in the innovation process (discovery and fundamental research) and that certainly must remain the focus of attention for the Foundation" (NSF 2008).

Coordinating support and strategically thinking about translating basic research into prototype products, processes, and services, and even early stages of technology development also fall clearly under the NSF purview. NSF has several programs that foster and encourage the translation of new knowledge generated through basic research into products, processes, services, and methodologies. Some of these programs (described below in the "Established Programs" section) are visualized in Figure 3 along the simplified innovation continuum. Many of these programs reside in the Directorate for Engineering (ENG), where they may take advantage of engineering's inherent focus on discoveries for practical ends (NSF 2008).

[4] Pasteur's Quadrant is a label given to research that seeks both fundamental understanding of scientific problems and benefit to society. Louis Pasteur's research is thought to exemplify this type of research. The term was introduced by Donald Stokes in his 1997 book, *Pasteur's Quadrant*.

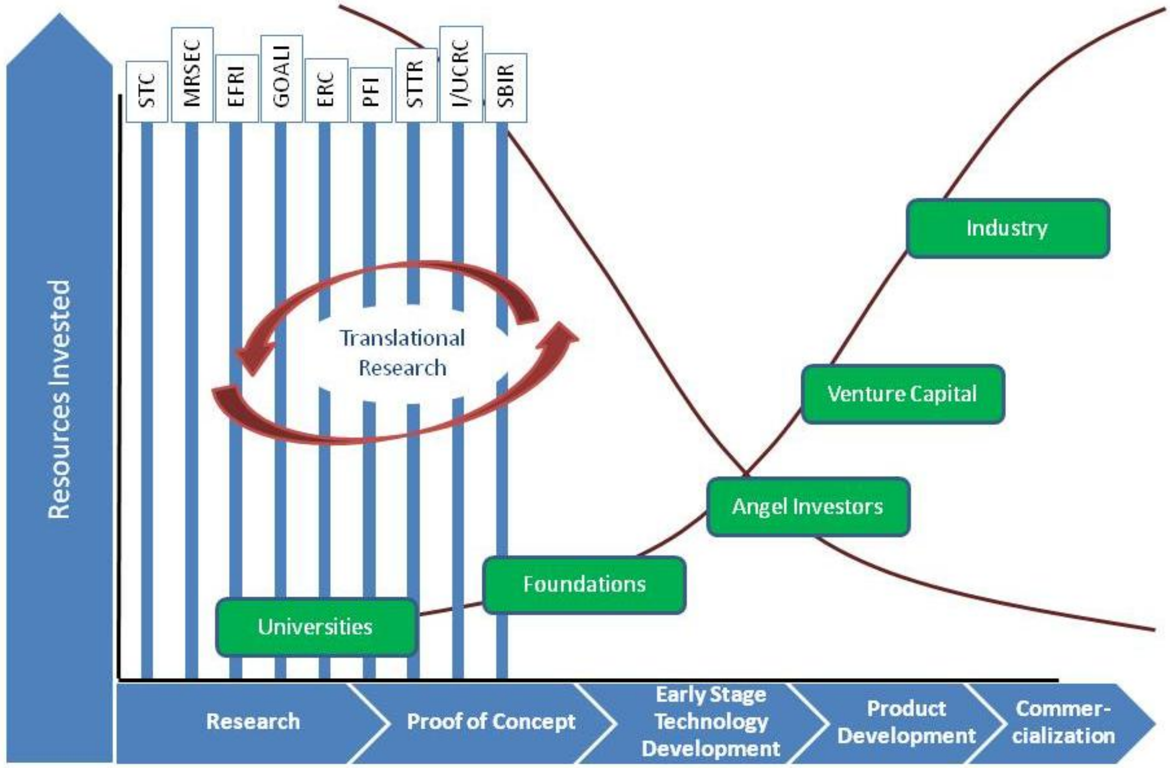

Figure 3: NSF programs supporting translational research represented along the linear innovation continuum

Challenges to the Innovation Ecosystem

The people, institutions, policies, and resources that promote the translation of new ideas into products and processes and services are generally recognized to comprise the *innovation ecosystem* (Freeman 1988; Nelson 2002; Foray 2009). While research and development (R&D) funding is a significant contributor to technological innovation, it is not the only factor that affects the success of the broadly defined innovation ecosystem.[5] Public policies include monetary policy, tax policy, standards, procurement, economic regulation, health care policy, market access, and others are important as well (Milbergs 2004). Not surprisingly, representations of the innovation ecosystem, as shown in Figure 4, are thus quite complex.

[5] Some have pointed out that many innovative companies do not engage in any R&D, and they create value through both technological and non-technological changes (Organisation for Economic Co-operation and Development 2010).

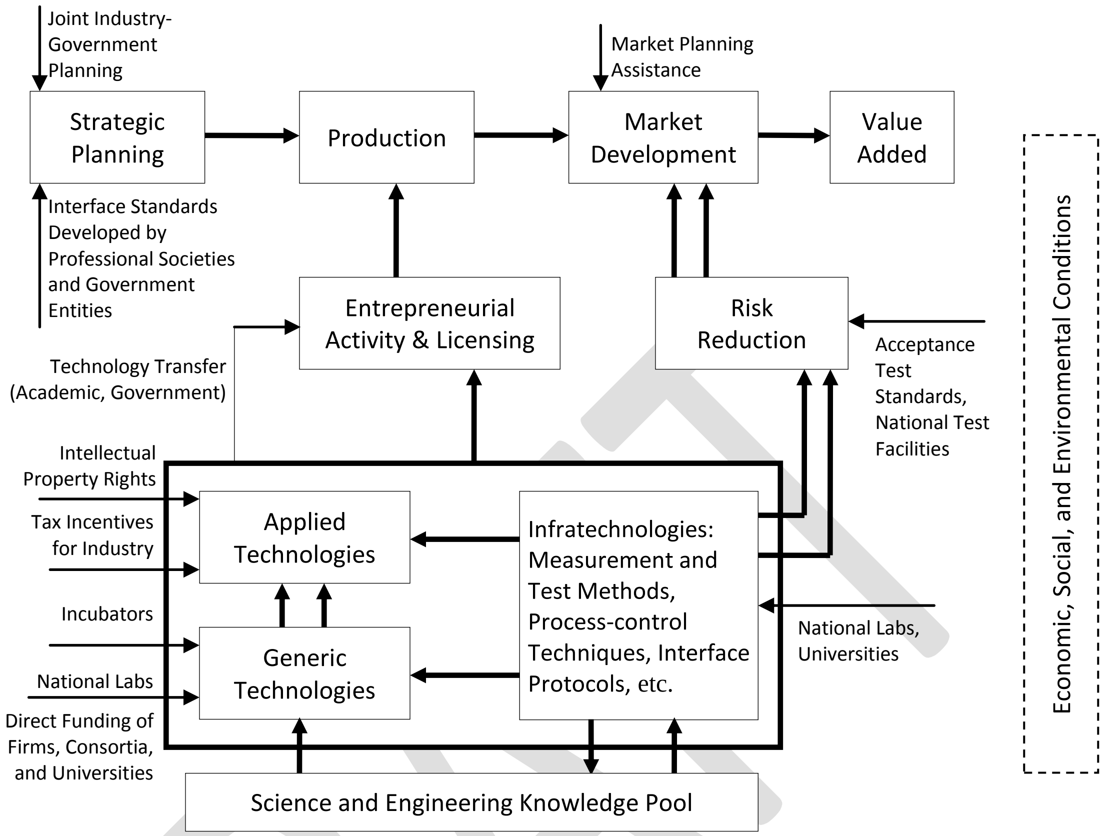

Figure 4: Representation of the U.S. innovation ecosystem
Source: Adapted from Tassey (2008)

The challenges around successful innovation and the funding gap, while recognized in the past, had been partially filled with robust angel and VC investments; and United States' leadership in both fundamental science and engineering research, and its conversion into commercial products, processes, and services. In recent years, however, certain trends have made this gap and its consequences more serious:

- Other countries have noted the benefits of science and engineering-based innovation and have developed strategies to explicitly capitalize on the translation of basic research findings. The globalization of science and engineering—both its process and outcomes—makes this global competition fiercer than it was in the past.[6]
- Due to both the shortened time horizon in the marketplace and the financial crisis, industry is much more reluctant to take on long-term, risky translational research.[7]

[6] The U.S. share of global R&D is declining, and the high-technology trade deficit continues to grow (NSF 2010b).
[7] Atkinson and Wial (2008) show that corporate R&D has moved away from basic and applied research towards development.

- The global financial crisis has reduced the flow of capital (including venture and angel funding) that once was more freely available for moving an idea from the basic research stage to a product.[8]

The policies that will be required to overcome these current challenges are many, and will require sustained efforts in government, industry, and academia. Important issues facing the innovation ecosystem such as trade policy, tax policy and access to capital markets will need to be addressed through other mechanisms and reforms.

Given the current challenges to the innovation ecosystem, both fundamental and translational research are more important than ever in supporting innovation. To better understand the obstacles facing translational research, NSF recently commissioned a study that found the following major barriers: insufficient resources; insufficient industry engagement in university research; and lack of talent flow across university–industry boundaries (Peterson 2010).

Responding to Innovation Challenges

The Obama Administration, recognizing the current threats to the innovation ecosystem, has developed a strategy to promote innovation in the U.S. (EOP 2009). This strategy, depicted in Figure 5, is built on three components: invest in the building blocks of American innovation; promote competitive markets that spur productive entrepreneurship; and catalyze breakthroughs for national priorities. NSF plays a strong role in this strategy by growing the scientific and technical capital (both knowledge and workforce) and by seeking and encouraging academic collaboration with innovation partners such as industry and economic entities.

Given the challenges facing both the innovation ecosystem broadly and translational research specifically, NSF proposes to strengthen its role and leadership in translational research and integrate it even more strongly with NSF's core mission of basic research and education. NSF is uniquely positioned to take advantage of its vast network of researchers and universities, to engage the most creative and consequential ideas and talents, and to attract industrial and economic partners in the translation of basic research into new innovations. Such an effort can take many forms: investments into human capital, creating closer university–industry ties in nurturing basic research, and sharing the work of translational research.

[8] Venture Capital funds are moving away from early-stage and seed funding (National Venture Capital Association 2010). Angel funds, while more difficult to track, also appear to be moving away from seed and startup capital (Center for Venture Research 2009).

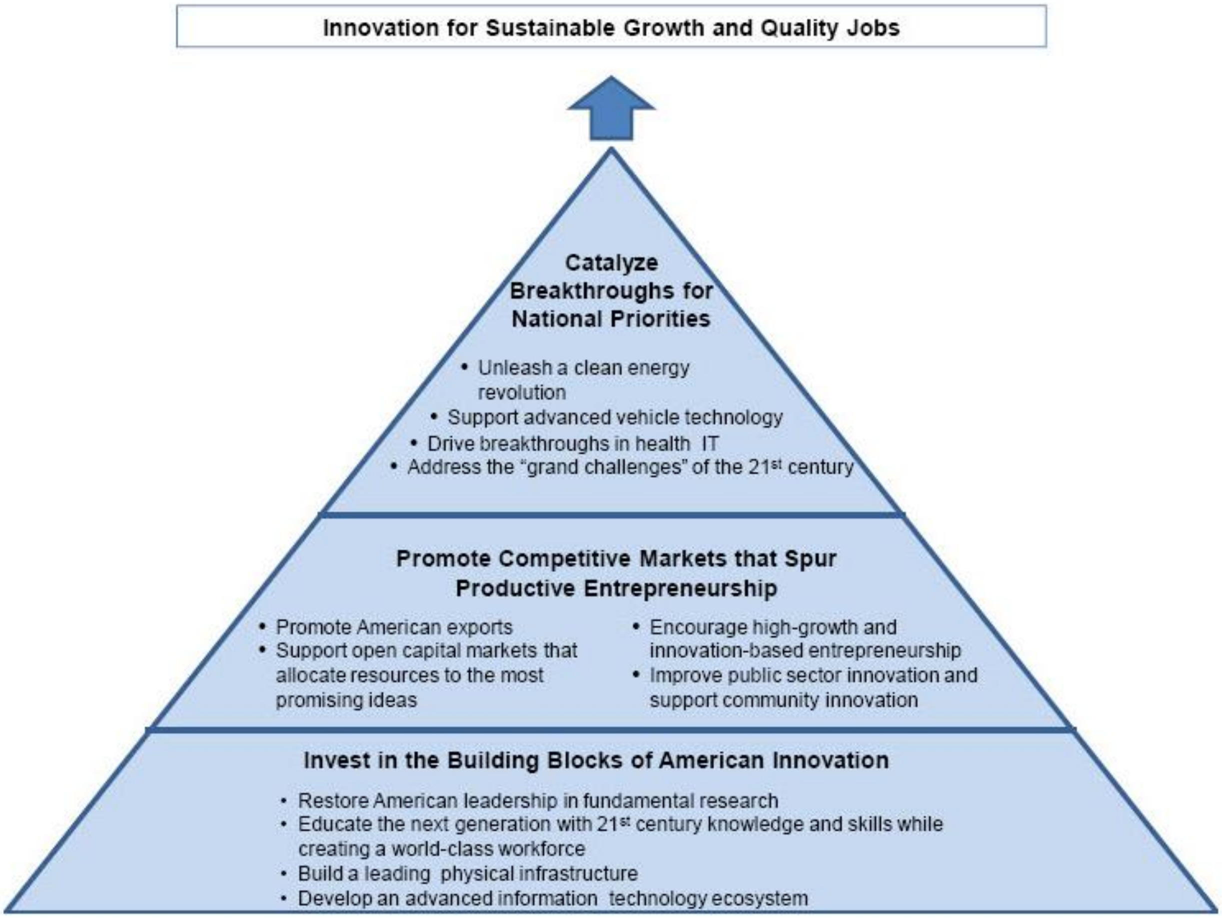

Figure 5: The Obama Administration's Innovation Strategy, composed of three parts: building blocks, competitive markets and productive entrepreneurship, and breakthroughs for national priorities.
Source: EOP (2009)

NSF can play a major role by strengthening and aligning some current programs, especially those that already emphasize translational research and innovation, and exploring the creation of new ones to fill gaps. These programs and activities will be grounded by characteristics that can overcome barriers identified above:

- **Resources: Spur Translation of Fundamental Research.** Fundamental science and engineering research frequently yields discoveries that promise societal benefits in areas such as sustainable energy, health care, and communications. To encourage technological innovation, NSF would provide funding opportunities for fundamental research that is explicitly aimed towards an end-use. To take advantage of results with potential for commercial development, NSF would enable academic researchers to take their fundamental research to the next phase via translational research opportunities that launch their idea toward proof of concept.

- **Industry Engagement: Encourage Collaboration between Academia and Industry**. Academia and industry may collaborate through the sharing of ideas, infrastructure, and people. Such collaboration encourages faculty and students to consider the commercial relevance and potential of their research and fosters their entrepreneurial skills. Individuals and larger centers now have opportunities for research partnership through NSF. With additional funding, these opportunities could be expanded to translate more fundamental research in more parts of the country, innovation could be more deeply infused in the education of future scientists and engineers, and academic researchers could help address the fundamental research challenges of industry.

- **Flow of Talent to Industry: Educate to Innovate**. To prepare U.S. students, particularly engineering students, to be *globally aware leaders in innovation*, education through this strategy should include a strong emphasis on entrepreneurship. These students must be steeped in the culture of innovation and take that mindset with them to either academia or industry. Successful programs will graduate more students who form startup companies or lead innovation teams in established firms. Strong programs will also encourage students to develop innovative commercial products or win patents while still in school.

As previously mentioned, several existing NSF programs that embody these features have already produced exciting discoveries that have led to new products, processes, and services in industry. They are described in the next section. Such successes could be multiplied with greater investment and coordination. Also described are pilot activities and new concepts that build on the knowledge and experience of NSF and are designed to provide additional opportunities or fill known gaps within the ecosystem framework.

Established programs

Engineering Research Centers (ERCs): The ERC program supports interdisciplinary teams and infrastructure that strategically join discovery with research that advances enabling systems technology in partnership with industry. Center education activities serve pre-college students and teachers through practicing engineers. Centers funded since 2008 have become more directly focused on bridging the innovation gap through partnerships with small firms and groups dedicated to entrepreneurship. (Other NSF center approaches, including NSECs, MRSECs, and STCs, have similar structures and results.) To date, 54 ERCs have formed, with 15 current ERCs operating within a 10-year window of NSF support. ERC awards **spur translation of fundamental research**, **encourage university–industry collaboration**, and **educate faculty and students to innovate**.

Industry/University Cooperative Research Centers (I/UCRCs): The I/UCRC program engages small interdisciplinary groups of faculty and students to perform research on industry-relevant and mutually agreed-upon topics, with industry and other stakeholders providing the majority of financial support (7 to 8 times the NSF investment). I/UCRCs **spur translation of fundamental research** and **encourage university-industry collaboration**.

Grant Opportunities for Academic Liaison with Industry (GOALI): This program promotes university–industry collaboration by supporting academic fellowships/traineeships in industry, industrial practitioners on campus, and industry–university team research. GOALI awards **spur**

translation of fundamental research, **encourage university-industry collaboration**, and **educate faculty and students to innovate**.

Partnerships for Innovation (PFI): The PFI program promotes partnerships between academe, the private sector, and government in order to: generate new ideas through collaborative research; transform new ideas into goods, businesses, or services to society; build infrastructure to enable innovation; and educate people to foster innovation. PFI outputs include knowledge and technology transfer, product commercialization, startup formation, workforce development, and education in the innovation enterprise in academia at all levels and in industry. PFI awards **spur translation of fundamental research**, **encourage university-industry collaboration**, and **educate faculty and students to innovate**.

Small Business Innovation Research (SBIR)/Small Business Technology Transfer (STTR): This investment stimulates technological innovation by strengthening the role of small business in meeting societal needs, increasing the commercial application of federally supported research results, and fostering participation by small businesses owned by socially and economically disadvantaged persons and women. SBIR and STTR grants **spur translation of fundamental research**, and **encourage university–industry collaboration**.

Pilot activities

Industry-defined Fundamental Research: In this pilot program, the Industrial Research Institute has invited its own members, professional society members, and university partners to examine possible research thrusts that are fundamental and that could have a transformative economic impact on an industry or sector. These research areas will then inform relevant research programs within ENG. These naturally can lead into any one of the above-referenced programs as a follow-up to the pilot program. This project will **spur translation of fundamental research** and **encourage university-industry collaboration**.

Industry Postdoctoral Fellows: Through an award to the American Society for Engineering Education, the NSF has provided 40 grants to postdoctoral students for innovation-focused work in industry, the costs of which are shared between industry and NSF. An expansion of this fellowship into NSF-supported small businesses (through SBIRs/STTRs) will be a natural follow-on program. This investment will **encourage university-industry collaboration** and **educate faculty and students to innovate**.

Innovation Fellows: This activity will support cohorts of engineering undergraduates in an innovation-focused Ph.D. graduate program that includes summer internships in industry. This investment will **spur translation of fundamental research**, **encourage university-industry collaboration**, and **educate faculty and students to innovate**.

Translational Research in the Academic Community (TRAC): TRAC supplements provide targeted resources to academic researchers to begin the translation of results from NSF GOALI fundamental research into potential commercial applications. Funds support prototyping, proof-of-concept tests, and/or scale-up. TRAC supplements **spur translation of fundamental research** and **educate faculty and students to innovate**.

Accelerating Innovation Research (AIR): The AIR pilot involves two related, new activities. The first will encourage the translation of technologically promising, fundamental discoveries made by NSF researchers, while drawing upon and building entrepreneurship in researchers and students. The second activity will foster connections between existing NSF research centers and other institutions, whose complementary foci will spur the development of discoveries into innovative technologies through collaboration. AIR awards will **spur translation of fundamental research**, **encourage university-industry collaboration**, and **educate faculty and students to innovate**.

Small Business Innovation Research (SBIR)/Small Business Technology Transfer (STTR): Recently, NSF partnered with the Economic Development Administration and the National Institutes of Health to launch the i6 Challenge, a competition that encourages technology commercialization and entrepreneurship.[9] NSF has also explicitly linked SBIRs with the ERCs and the I/UCRCs. SBIR and STTR grants **spur translation of fundamental research** and **encourage university–industry collaboration**.

New concepts

University–Industry Collaboration to Advance Discovery: Modeled after the GOALI program, this program would accelerate innovation based on the transformational research already funded by the ENG Office of Emerging Frontiers in Research and Innovation (EFRI) by providing incentives to industry researchers to partner with EFRI grantees. As a first attempt to implement this idea, the FY 2010 EFRI solicitation allows industry researchers to serve as co-PIs on a research project. This investment will **spur translation of fundamental research** and **encourage university–industry collaboration**.

Economic Development Stimulation in Rural Areas: A program sharing many features of the ERCs could be established for universities in rural areas that have a history of working effectively with local or national industries. Such a program would provide students, faculty, and the region with the positive effects of ERCs: opportunities to participate in large-scale research projects; new curricula and pedagogical tools; building a culture of innovation through outreach and collaboration with other universities and industry. These awards would **spur translation of fundamental research**, **encourage university–industry collaboration**, and **educate faculty and students to innovate**.

National Network for Technology Integration (NNTI): Technology integration and scale-up are critical components of technology translation and often neglected as discoveries are matured towards commercial products. The NNTI would address this issue by providing a network of technology-specific flexible user facilities that provide access to state-of-the-art instruments and services for technology integration and for scale-up and manufacturing research, and they would offer training and education opportunities. The NNTI would connect to regional innovation hubs to facilitate collaboration with industry. These awards would **spur translation of fundamental research**, **encourage university–industry collaboration**, and **educate faculty and students to innovate**.

[9] Read more about the i6 Challenge at EDA's Web site, http://www.eda.gov/i6.

An NSF Vision of the Innovation Ecosystem

Through the creation and strengthening of NSF activities and programs, as well as through links with other government agencies, NSF will build a culture of innovation among faculty and students, promote regional coordination and linkages, and develop technology-based networks of researchers. These contributions to the innovation ecosystem will penetrate deeply and broadly across the country to engage the most creative and consequential ideas and talents in the process of innovation. The NSF ecosystem will involve research universities and teaching-oriented institutions serving diverse populations, throughout all geographic regions.[10] In addition, NSF will engage large and small groups of faculty as well as individual researchers, at one or multiple institutions. By instilling an understanding of innovation and providing opportunities for knowledge transfer between academia and industry, NSF will equip more faculty and students to be creative leaders of technology.

NSF's enhanced contribution to the innovation ecosystem described here will enable American colleges and universities to become "engines of innovation" that operate in close partnership with industry in any arena of advanced technology, from new approaches to energy generation and use and advanced information technologies to cybersecurity and bioengineering. The ultimate goal is to extend America's historical reputation for ingenuity to a new recognition as "a nation of innovators." Opportunities for economic benefits from this enhanced innovation would be available to companies of all sizes and types, to a broader spectrum of Americans, and across all geographic locations. And it could produce graduates who are capable of continuing the translational innovation envisioned here out into the future to sustain U.S. technological leadership and economic vitality for generations to come.

[10] For example, NSF might engage the participation of U.S. engineering undergraduates, 25 percent of whom are enrolled at institutions in states that participate in NSF's Experimental Program to Stimulate Competitive Research (EPSCoR).

References

Atkinson, R., and H. Wial. 2008. Boosting productivity, innovation, and growth through a national innovation foundation. Brookings.

Auerswald, P. E., and L. M. Branscomb. 2003. Valleys of death and Darwinian seas: financing the invention to innovation transition in the United States, *Journal of Technology Transfer*. 28:227–239.

Center for Venture Research. The angel investor market in 2009: Holding steady but changes in seed and startup investments. http://wsbe.unh.edu/files/2009_Analysis_Report.pdf.

Executive Office of the President. 2009. A strategy for American innovation: Driving towards sustainable growth and quality jobs. http://www.whitehouse.gov/assets/documents/SEPT_20__Innovation_Whitepaper_FINAL.pdf.

Foray, D. 2009. *The new economics of technology policy*. Northampton, MA: Elgar Publishing.

Freeman, C. 1988. "Japan: A new national innovation system?" in G. Dosi, C. Freeman, R. R. Nelson, G. Silverberg and L. Soete (eds.) Technology and economy theory, London: Pinter.

Mansfield, Edwin (1990), "Academic Research and Industrial Innovation," *Research Policy* 20: 1–12.

Milbergs, E. 2004. *Measuring innovation for national prosperity: Innovation framework report*.

National Venture Capital Association. 2010. Latest industry stats. http://www.nvca.org/index.php?option=com_content&view=article&id=78:latest-industry-statistics&catid=40:research&Itemid=102.

National Science Foundation. 1994–2010. Federal Funds for R&D. http://www.nsf.gov/statistics/fedfunds/

National Science Foundation. 2008. Engineering Advisory Committee. Encouraging industry-university partnerships.

National Science Foundation. 2010a. National Science Board. *Science and engineering indicators 2010*. http://www.nsf.gov/statistics/seind10/.

National Science Foundation. 2010b. Dear colleague letter: Supplemental opportunity for translational research in the academic community (TRAC). http://www.nsf.gov/pubs/2010/nsf10044/nsf10044.jsp.

Nelson, R. 2002. National Innovation Systems: A Retrospective on a Study in "Systems of Innovation: Growth, Competitiveness, and Employment," Vol. 2. Elgar Publishing: Northampton, MA.

NSF (see National Science Foundation)

Organisation for Economic Co-operation and Development. 2010. *The OECD innovation strategy: Getting a head start on tomorrow*.

http://www.oecd.org/document/15/0,3343,en_2649_34273_45154895_1_1_1_1,00.html#TOC
.

Stokes, D. 1997. *Pasteur's Quadrant: Basic Science and Technological Innovation*. Washington, DC: Brookings Institution Press.

Stone, A., S. Rose, B. Lal, and S. Shipp. 2008. Measuring innovation and intangibles: A business perspective. Science and Technology Policy Institute. IDA Document D-3704. http://www.athenaalliance.org/pdf/MeasuringInnovationandIntangibles-STPI-BEA.pdf.

Tassey, G. 2008. Globalization of technology-based growth: the policy imperative. *Journal of Technology Transfer* 33:560-578.

Tassey, G. 2009. Annotated bibliography of technology's impacts on economic growth. http://www.nist.gov/director/planning/upload/economic_impacts_of_technology.pdf.

Peterson, Thomas W. 2010. Assistant Director, Directorate for Engineering, National Science Foundation. From the lab bench to the marketplace: Improving technology transfer. Testimony before the Committee on Science and Technology. Subcommittee on Research and Science Education. June 10, 2010.

Wessner, C. 2008. An Assessment of the SBIR Program. National Academies Press.