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The National Nanotechnology Initiative: Overview, Reauthorization, and Appropriations Issues

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The National Nanotechnology Initiative: Overview, Reauthorization, and Appropriations Issues

Summary

Nanotechnology — a term encompassing the science, engineering, and applications of submicron materials — involves the harnessing of unique physical, chemical, and biological properties of nanoscale substances in fundamentally new and useful ways. The economic and societal promise of nanotechnology has led to substantial and sustained investments by governments and companies around the world. In 2000, the United States launched the world's first national nanotechnology program. Since then, the federal government has invested more than $8 billion in nanoscale science, engineering, and technology through the U.S. National Nanotechnology Initiative (NNI). U.S. companies and state governments have invested billions more. As a result of this focus and these investments, the United States has, in the view of many experts, emerged as a global leader in nanotechnology. However, the competition for global leadership in nanotechnology is intensifying as countries and companies around the world increase their investments.

Nanotechnology's complexity and intricacies, early stage of development (with commercial pay-off possibly years away), and broad scope of potential applications engender a wide range of public policy issues. Maintaining U.S. technological and commercial leadership in nanotechnology poses a variety of technical and policy challenges, including development of technologies that will enable commercial scale manufacturing of nanotechnology materials and products; environmental, health, and safety (EHS) concerns; and maintenance of public confidence in its safety.

Congress established programs, assigned responsibilities, and initiated research and development (R&D) related to these issues in the 21st Century Nanotechnology Research and Development Act of 2003 (P.L. 108-153). While many provisions of this act have no sunset provision, FY2008 is the last year of agency authorizations included in the act. Consideration may be given to reauthorization of this act in 2008.

Proponents of the NNI assert that nanotechnology is one of the most important emerging and enabling technologies and that U.S. competitiveness, technological leadership, national security, and societal interests require an aggressive approach to the development and commercialization of nanotechnology.

Critics of the NNI voice concerns that reflect disparate underlying beliefs. Some critics assert that the government is not doing enough to move technology from the laboratory into the marketplace. Others argue that the magnitude of the public investment may skew what should be market-based decisions in research, development, and commercialization. Still other critics say that the inherent risks of nanotechnology are not being addressed in a timely or effective manner.

From the NNI's inception through FY2008, Congress has appropriated a total of $8.5 billion for NNI activities. NNI funding in FY2008 is estimated to be $1.491 billion. For FY2009, President Bush requested $1.527 billion for the NNI.

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Introduction

Nanotechnology has been an issue of interest to Congress for a number of years, coming into focus in 2000 with the launch of the U.S. National Nanotechnology Initiative (NNI) by President Clinton in his FY2001 budget request to Congress. Since then, Congress has appropriated more than $8 billion for nanotechnology research and development (R&D). These efforts have been directed at advancing understanding and control of matter at the nanoscale,[1] where the physical, chemical, and biological properties of materials differ in fundamental and useful ways from the properties of individual atoms or bulk matter.[2]

The development and application of nanotechnology — more fully explained below — across a wide array of products and industries holds the potential for significant economic and societal benefits. To capture these benefits, the United States will have to effectively address a variety of technical and policy challenges that stand as potential barriers to commercialization, including environmental, health, and safety concerns and their implications for workplace, environmental, food, and drug regulations; development of standards, reference materials, and consistent nomenclature; development of new measurement methods and tools; effective technology transfer to the private sector; protection of intellectual property; availability, affordability, and patience of investment capital; ethical, legal, and societal concerns; public understanding, support, and acceptance; and development of a world-class scientific and technical nanotechnology workforce.

In 2003, Congress passed the 21st Century Nanotechnology Research and Development Act (P.L. 108-153) providing a legislative foundation for some of the activities of the NNI, authorizing agency funding levels through FY2008, and intended to address several of these challenges. Discussions are underway with respect to the possible reauthorization of this act in 2008. Congress may use this opportunity to further address these issues and to establish authorization levels for agency nanotechnology R&D. Alternatively, Congress may choose to address these issues in separate legislation. Several bills were introduced in the first session of the 110th Congress to address specific nanotechnology issues.

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[1] In the context of the NNI and nanotechnology, the nanoscale refers to a dimension of 1 to 100 nanometers (see box below).

[2] While extensive R&D has been, and continues to be, conducted to understand and harness the properties of individual atoms, this is not the domain of nanotechnology.

This report provides an overview of nanotechnology, the National Nanotechnology Initiative, possible reauthorization of the 21st Century Nanotechnology Research and Development Act of 2003 (P.L. 108-153), and appropriations issues.

Overview

Nanotechnology: A Description

The term "nanotechnology" is often used as an all-encompassing term for nanoscale science, engineering, and technology. Nanotechnology is the understanding and control of matter at dimensions of roughly 1 to 100 nanometers, the size-scale between individual atoms and bulk materials, where unique phenomena enable novel applications. A nanometer is one-billionth of a meter, or about the width of 10 hydrogen atoms arranged side-by-side in a line. Nanotechnology involves imaging, measuring, modeling, and manipulating matter at this size-scale.

At the nanoscale, the physical, chemical, and biological properties of materials differ in fundamental and useful ways from the properties of individual atoms and molecules or bulk matter. Nanotechnology R&D is directed toward understanding and creating improved materials, devices, and systems that exploit these new properties.

Physicist Richard Feynman's remarks at the 1959 annual meeting of the American Physical Society are often cited as the first articulation of and vision for nanotechnology. Though he did not use the term nanotechnology in this speech, he spoke of controlling matter at the nanoscale and creating atomic-level machines, positing some of the applications that doing so might enable.

Source: *The National Nanotechnology Initiative Strategic Plan, 2004*, Nanoscale Science, Engineering, and Technology Subcommittee, National Science and Technology Council, The White House, December 2004.

The economic and societal promise of nanotechnology has led to involvement and investments by governments and companies around the world. In 2000, the United States became the first nation to establish a formal, national initiative to advance nanoscale science, engineering, and technology — the National Nanotechnology Initiative. Since then, Congress has appropriated more than $8 billion in nanoscale science, engineering, and technology through the NNI. U.S. companies and state governments have invested billions more.

As a result of this focus and these investments, the United States has emerged as a global leader in nanotechnology. However, the competition for global leadership is intensifying as foreign investments in nanoscale science, engineering, and technology increase. Other nations have followed the U.S. lead and established their own national nanotechnology programs, each with varying degrees of investment, foci, and support for industrial applications and commercialization. Today, almost every nation that supports R&D has a national-level nanotechnology program.

Global nanotechnology investment in 2006 has been estimated at $12.4 billion, with public investments accounting for approximately $6.4

billion.[3] While the United States leads all other nations in public investments in nanotechnology R&D, it is estimated to account for only about a quarter of global annual public investments.[4]

Global investments in nanotechnology already have begun to yield economic benefits as products incorporating nanotechnology enter the marketplace. These products are estimated to have produced $50 billion in revenues in 2006.[5] By tapping the unique properties that emerge at the nanoscale, proponents maintain that nanotechnology holds the potential for products that could transform existing industries and create new ones, clean and protect the environment, extend and improve the quality of our lives, and strengthen the national security. Most nanotechnology products currently on the market — such as faster computer processors, higher density memory devices, lighter-weight auto parts, stain-resistant clothing, antibiotic bandages, cosmetics, and clear sunscreen — are evolutionary in nature, offering incremental improvements in characteristics such as performance, aesthetics, cost, size, and weight.

Evolutionary nanotechnology products, however, represent only a small fraction of what many see as the substantial longer-term economic and societal promise of nanotechnology. One estimate projects nanotechnology product revenues will reach $2.6 trillion[6] by 2014, or 15% of global manufacturing output, while another estimates global revenues will reach $2.95 trillion by 2015, of which almost half will come from semiconductors.[7, 8]

Many nanotechnology advocates — including business executives, scientists, engineers, medical professionals, and venture capitalists — assert that in the longer term, nanotechnology, especially in combination with information technology, biotechnology, and the cognitive sciences, may deliver revolutionary advances, including:

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[3] *Profiting From International Nanotechnology*, Lux Research, December 2006.

[4] *The National Nanotechnology Initiative at Five Years: Assessment and Recommendations of the National Nanotechnology Advisory Panel*, President's Council of Advisors on Science and Technology, May 2005.

[5] "Nanotechnology Moves from Discovery to Commercialization," press release, Lux Research, November 20, 2007. [http://www.luxresearchinc.com/press/2007-lux-research-nanotech-report-5.pdf]

[6] *Sizing Nanotechnology's Value Chain*, Lux Research, 2004.

[7] *Halfway to the Trillion Dollar Market: A Critical Review of the Diffusion of Nanotechnologies*, Cientifica, 2007. [http://www.cientifica.eu/files/Whitepapers/A%20Reassessment%20of%20the%20Trillion%20WP.pdf]

[8] While views vary on how to calculate nanotechnology's contribution to these products, the consensus is that nanotechnology is likely to have a significant economic impact and transformative effect on many industries.

- new prevention, detection, and treatment technologies that could reduce substantially death and suffering from cancer and other deadly illnesses;[9]

- new organs to replace damaged or diseased ones;[10]

- contact lenses, skin patches, and glucose-sensing tattoos that monitor diabetics' blood sugar levels and warn when too high or low;[11]

- clothing that protects against toxins and pathogens;[12]

- clean, inexpensive, renewable power through energy creation, storage, and transmission technologies;[13]

- inexpensive, portable water purification systems that provide universal access to safe water;[14]

- energy efficient, low-emission "green" manufacturing systems;[15]

- high-density memory systems capable of storing the entire Library of Congress collection on a device the size of a sugar cube;[16]

- agricultural technologies that increase crop yield and improve nutritional value, reducing global hunger and malnutrition;[17]

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[9] National Cancer Institute website. [http://nano.cancer.gov/resource_center/tech_backgrounder.asp]

[10] Ibid.

[11] Aslan, Kadir; Lakowicz, Joseph R.; and Geddes, Chris D. "Nanogold plasmon resonance-based glucose sensing. Wavelength-ratiometric resonance light scattering," *Analytical Chemistry*, 2005, Vol. 77. *Strategic Plan for Pediatric Urology*, National Institute of Diabetes and Digestive and Kidney Disease, National Institutes of Health, Department of Health and Human Services, February 2006.

[12] Risbud, Aditi. "Fruit of the Nano Loom," *Technology Review*, February 2006.

[13] *Nanoscience Research for Energy Needs*, Nanoscale Science, Engineering, and Technology Subcommittee, National Science and Technology Council, The White House, December 2004.

[14] Risbud, Aditi. "Cheap Drinking Water from the Ocean," *Technology Review*, June 2006.

[15] Selko, Adrienne. "New Nanotechnology-Based Coatings Are Energy Efficient and Environmentally Sound," *Industry Week*, August 22, 2007. "Tomorrow's Green Nanofactories," *Science Daily*, July 11, 2007.

[16] *National Nanotechnology Initiative — Leading to the Next Industrial Revolution*, Interagency Working Group on Nanoscience, Engineering, and Technology, National Science and Technology Council, The White House. [http://www.ostp.gov/NSTC/html/iwgn/iwgn.fy01budsuppl/nni.pdf]

[17] *21st Century Agriculture: A Critical Role for Science and Technology*, U.S. Department

(continued...)

- self-repairing materials;[18]

- powerful, small, inexpensive sensors that can warn of minute levels of toxins and pathogens in air, soil, or water;[19] and

- decontaminated industrial sites through environmental remediation.[20]

Although some applications of nanotechnology have proven market-ready, much fundamental research remains ahead, including efforts to advance understanding of nanoscale phenomena; characterize nanoscale materials; understand how to control and manipulate nanoscale particles; develop instrumentation and measurement methods; and understand how nanoscale particles interact with humans, animals, plants, and the environment. In addition, several federal agencies — such as the Departments of Defense, Energy, and Homeland Security — see the potential for nanotechnology to help address mission requirements. Historically, the federal government has played a central role in funding these types of research and development activities.

Though federal nanoscale science, engineering, and technology R&D had been underway for over a decade, the NNI was first initiated as a Presidential technology initiative in 2000.[21] The original participating agencies were the National Science Foundation (NSF), the Department of Defense (DOD), the Department of Energy (DOE), the Department of Commerce's (DOC) National Institute of Standards and Technology (NIST), the National Aeronautics and Space Administration (NASA), and the Department of Health and Human Services' National Institutes of Health (NIH). In 2007, 25 agencies participated in the NNI, including 13 that received appropriations to conduct and/or fund nanotechnology R&D.

Since its first year of funding in FY2001, the NNI's annual appropriations have grown three-fold to an estimated $1.491 billion in FY2008. From FY2001 through

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[17] (...continued)
of Agriculture, June 2003; and *Nanoscale Science and Engineering for Agriculture and Food Systems*: *Draft Report of the National Planning Workshop to the Cooperative State Research, Education, and Extension Service of the U.S. Department of Agriculture*, July 2003.

[18] *Nanotechnology in Space Exploration*, Nanoscale Science, Engineering, and Technology Subcommittee, National Science and Technology Council, The White House, August 2004.

[19] *Nanotechnology and the Environment*, Nanoscale Science, Engineering, and Technology Subcommittee, National Science and Technology Council, The White House, May 2003.

[20] *Proceedings of the U.S. Environmental Protection Agency Workshop on Nanotechnology for Site Remediation,* U.S. Environmental Protection Agency, October 2005.

[21] "National Nanotechnology Initiative: Leading to the Next Industrial Revolution," press release, The White House, January 21, 2000. [http://clinton4.nara.gov/WH/New/html/20000121_4.html]; and "Steering the technology that will redefine life as we know it," *Industrial Biotechnology*, Vol. 1, No. 3, Fall 2005. [http://www.nsf.gov/crssprgm/nano/reports/mcr_ind_biotech_interview.pdf]

FY2008, Congress appropriated a total of $8.5 billion for NNI activities. President Bush has requested $1.527 billion for the NNI in FY2009.

In 2003, Congress provided a statutory foundation for some of the activities of the NNI through the 21st Century Nanotechnology Research and Development Act of 2003 (P.L. 108-153). The act established a National Nanotechnology Program (NNP) and provided authorizations for a subset of the NNI agencies, namely the NSF, DOE, NASA, NIST, and Environmental Protection Agency (EPA). The act, however, did not address the participation of several agencies that fund nanotechnology R&D under the NNI, including DOD, NIH, and the Department of Homeland Security (DHS). Nevertheless, coordination of nanotechnology R&D activities across all NNI funding agencies continues under the National Science and Technology Council's (NSTC's) Nanoscale Science, Engineering, and Technology (NSET) subcommittee.[22] According to the NSET subcommittee's 2004 NNI Strategic Plan, "For continuity and to capture this broader participation, the coordinated federal activities as a whole will continue to be referred to as the National Nanotechnology Initiative." Accordingly, the functions and activities established under the act are incorporated into the Executive Branch's implementation of the NNI.

While many provisions of this act have no sunset provision, FY2008 is the last year of agency authorizations included in the act. Discussions are underway regarding the potential reauthorization of this act in 2008.

The thrust of the NNI has primarily been the development of fundamental scientific knowledge through basic research. Investments at mission agencies, such as DOD, have supported nanotechnology applications development for which they are a primary customer. Other investments have supported infrastructural technologies. For example, NIST has contributed to developing tools and standards that enable measurement and control of matter at the nanoscale, thereby supporting the conduct of R&D and the ability to manufacture nanoscale materials and products. As understanding of nanotechnology has matured, the NNI has worked with a variety of industry organizations to facilitate the movement of research results from the laboratory bench to the marketplace in fields as disparate as semiconductors, chemicals, energy, concrete, and forest products.

The NNI agencies also have begun to address research needs and regulatory issues related to environmental, health, and safety issues, as well as issues such as public understanding and workforce education and training. The NNI agencies actively engage in a variety of international fora, such as the Organization for Economic Cooperation and Development (OECD) and the International Standards

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[22] Prior to P.L. 108-153, the Bob Stump Defense Authorization Act for Fiscal Year 2003 (P.L. 107-314) required DOD to "provide for interagency cooperation and collaboration on nanoscale research and development." The NSET subcommittee is a subcommittee of the NSTC Committee on Technology.

Organization (ISO), to cooperatively address nanotechnology issues related to EHS, metrology[23] and standards, nomenclature, and nanoscale materials characterization.

Maintaining U.S. leadership poses a variety of technical, economic, and policy challenges, including:

- safeguarding the environment and ensuring human health and safety;
- creating the standards, reference materials, nomenclature, methods, and tools for metrology to enable the manufacturing of nanoscale materials and products;
- developing a world-class scientific and technical nanotechnology workforce;
- translating research results into products, including effective technology transfer to the private sector;
- understanding public perceptions and attitudes and fostering public understanding;
- addressing ethical, legal and societal implications;
- protecting intellectual property;
- securing investment capital for early-stage research, development, and commercialization; and
- fostering and facilitating international cooperation and coordination.

Proponents of the NNI assert that nanotechnology is one of the most important emerging and enabling technologies[24] and that U.S. competitiveness, technological leadership, national security and societal interests require an aggressive approach to the development and commercialization of nanotechnology. Critics of the NNI hold a variety of competing views, asserting that government is not doing enough, is doing too much, or is moving too quickly.

Some in industry have criticized the NNI for being overly focused on basic research and not being aggressive enough in moving NNI-funded R&D out of government and university laboratories and into industry. Others in industry have criticized the federal government for not providing mechanisms to help advance nanotechnology R&D to the point where it becomes economically viable for venture capitalists, corporations, and other investors to create products and bring them to

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[23] Metrology is the science of measurement, including the equipment and processes used to produce a measurement.

[24] The Department of Commerce characterizes emerging and enabling technologies as those that "offer a wide breadth of potential application and form an important technical basis for future commercial applications." (ATP Rule, 15 C.F.R. Part 295).

market. Some refer to this gap as the "valley of death."[25] Still others in industry have criticized the NNI for not adequately supporting the development of metrology, standards, equipment, and processes necessary to manufacture nanotechnology materials, products, and systems at a commercial scale.

Conversely, supporters of industry-driven market investments contend that extensive government support for nanotechnology may supplant the judgment of the marketplace by picking "winners and losers" in technological development. For example, the size and directions of the NNI investments may encourage industry to follow the government's lead rather than independently selecting R&D directions itself or, alternatively, may result in the promotion of a less effective technology path over a more effective one. These supporters also assert that federal government funding of scientific research is often wasteful, driven by political considerations and not scientific merit.[26]

Some non-governmental organizations (NGO) are critical of nanotechnology for its potential adverse impacts on human health and safety and on the environment. They assert that the government is pushing ahead too quickly in developing nanotechnology and encouraging its commercialization and use without adequately investing in research focused on understanding and mitigating negative EHS implications.[27] They argue that the very characteristics that make nanotechnology promising also present significant potential risks to human health and safety and the environment. Some of these critics argue for application of the "precautionary principle," which holds that regulatory action may be required to control potentially hazardous substances even before a causal link has been established by scientific

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[25] The term "valley of death" is used by business executives, economists, and venture capitalists to describe the development gap that often exists between a laboratory discovery and the market's willingness to invest to advance the discovery to a final commercial product. This gap occurs due to a variety of issues, such as technical risk, market uncertainty, and likelihood of obtaining an adequate return on investment.

[26] Crews, Clyde Wayne, Jr., "Washington's Big Little Pork Barrel: Nanotechnology," Cato Institute website, May 29, 2003. [http://www.cato.org/pub_display.php?pub_id=3110]

[27] Testimony of Andrew Maynard, Chief Science Advisor, Project on Emerging Nanotechnologies, Woodrow Wilson International Center for Scholars, "Research on Environmental and Safety Impacts of Nanotechnology: Current Status of Planning and Implementation under the National Nanotechnology Initiative," hearing, Subcommittee on Research and Science Education, House Committee on Science and Technology, October 31, 2007.

evidence.[28] At least one NGO has called for a moratorium on nanotechnology R&D and new commercial products incorporating synthetic nanoparticles.[29]

National Nanotechnology Initiative

The National Nanotechnology Initiative is an interagency program that coordinates federal nanoscale science, engineering, and technology R&D activities and related efforts among participating agencies.

Vision and Goals

The National Science and Technology Council (NSTC) has stated the following vision for the NNI:

> A future in which the ability to understand and control matter on the nanoscale leads to a revolution in technology and industry. The NNI will expedite the discovery, development, and deployment of nanotechnology in order to achieve responsible and sustainable economic benefits, to enhance the quality of life, and to promote national security.[30]

To achieve its vision, the NNI has established four goals: maintain a world-class R&D program aimed at realizing the full potential of nanotechnology; facilitate transfer of new technologies into products that provide economic growth, jobs, and other public benefits; develop educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology; and support responsible development of nanotechnology.[31]

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[28] "NGOs urge precautionary principle in use of nanomaterials," EurActiv.com, June 14, 2007. [http://www.euractiv.com/en/environment/ngos-urge-precautionary-principle-use-nanomaterials/article-164619] Sass, Jennifer. "Nanotechnology and the Precautionary Principle," presentation, Natural Resources Defense Council, 2006. [http://docs.nrdc.org/health/hea_06121402a.pdf] The precautionary principle has been used in other countries on some issues. For example, the Biosafety Protocol to the 1992 Convention on Biological Diversity incorporates provisions applying the precautionary principle to the safe handling, transfer, and trade of genetically modified organisms. For further information, see CRS Report RL30594, *Biosafety Protocol for Genetically Modified Organisms: Overview*, by Alejandro E. Segarra and Susan R. Fletcher.

[29] "No Small Matter II: The Case for a Global Moratorium — Size Matters!," Occasional Paper Series, ETC Group, April 2003. [http://www.etcgroup.org/upload/publication/pdf_file/165]

[30] *The National Nanotechnology Initiative Strategic Plan*, Nanoscale Science, Engineering, and Technology Subcommittee, National Science and Technology Council, The White House, December 2004.

[31] Ibid.

History

Attempts to coordinate federal nanoscale R&D began in November 1996, as staff members from several agencies met regularly to discuss their plans and programs in nanoscale science and technology. This group continued informally until September 1998, when it was designated as the Interagency Working Group on Nanotechnology (IWGN) under the NSTC. In August 1999, IWGN completed its first draft of a plan for an initiative in nanoscale science and technology, which was subsequently approved by the President's Council of Advisors on Science and Technology (PCAST) and the White House Office of Science and Technology Policy (OSTP).[32]

In his 2001 budget submission to Congress, then-President Clinton raised nanotechnology-related research to the level of a federal initiative, officially referring to it as the National Nanotechnology Initiative.[33]

Legislative Approach

Congress has played a central role in the National Nanotechnology Initiative, providing appropriations for the conduct of nanoscale science, engineering, and technology research; establishing programs; and creating a legislative foundation for the activities of the NNI.

Congressional funding for the NNI is provided through appropriations to each of the NNI-participating agencies. The NNI has no centralized funding. The overall NNI budget is calculated by aggregating the nanotechnology budgets for each of the federal agencies that conduct or provide funding for nanoscale science, engineering, and technology research.

In FY2001, the first year of NNI funding, Congress provided $464 million to eight agencies for nanoscale science, engineering, and technology research.[34] The NNI has continued to receive support from both Congress and the White House. Both the number of agencies participating in the NNI and the size of the federal investment have grown. Today 25 agencies participate in the NNI, 13 of which

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[32] National Nanotechnology Initiative website. [http://www.nano.gov/html/about/history.html]

[33] "National Nanotechnology Initiative: Leading to the Next Industrial Revolution," press release, The White House, January 21, 2000. [http://clinton4.nara.gov/WH/New/html/20000121_4.html]; and National Nanotechnology Initiative website. [http://www.nano.gov/html/about/history.html]

[34] In its January 21, 2001 press release, "National Nanotechnology Initiative: Leading to the Next Industrial Revolution," announcing the establishment of the NNI, the White House identified only six participating agencies — NSF, DOD, DOE, NIST, NASA, and NIH. Subsequently, EPA and DOJ reported nanotechnology R&D funding in FY2001, bringing the total number of agencies funding nanotechnology R&D in FY2001 to eight.

received appropriated funds for nanotechnology R&D in FY2007.[35] Total NNI funding in FY2008 was $1.491 billion, more than three times the level of funding provided in FY2001. The original six agencies identified at the launch of the NNI[36] still account for the vast majority of NNI funding, 98.3% in FY2008.

Some of the NNI's activities were codified and further defined in the 21st Century Nanotechnology Research and Development Act of 2003 which was passed by Congress in November 2003. On December 3, 2003, the act was signed into law (P.L. 108-153) by President Bush.[37] The legislation received strong bipartisan support in both the House of Representatives, which passed the bill on a recorded vote of 405-19, and in the Senate, which passed the bill by unanimous consent.

Though this act is often referred to as the enabling legislation for the National Nanotechnology Initiative, the act actually establishes a National Nanotechnology Program (NNP). The act provides authorizations for five NNI agencies — the National Science Foundation, Department of Energy, NASA, National Institute of Standards and Technology, and Environmental Protection Agency — but not for the Department of Defense, National Institutes of Health, Department of Homeland Security,[38] or other NNI research agencies that collectively accounted for 46% of NNI funding in FY2003.

The act created the NNP for the purposes of establishing the goals, priorities, and metrics for evaluation of federal nanotechnology research, development, and other activities; investing in federal R&D programs in nanotechnology and related sciences to achieve those goals; and providing for interagency coordination of federal nanotechnology research, development, and other activities undertaken pursuant to the NNP.

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[35] NNI participants include agencies that either conduct or provide funding for nanotechnology R&D, as well as agencies with missions that may affect the development, commercialization, and use of nanotechnology. For example, in the latter case, the Food and Drug Administration may regulate (or not regulate) nanotechnology products, the U.S. Patent and Trademark Office's (USPTO) treatment of nanotechnology-related patents may affect the value of the underlying intellectual property, and the execution of the missions of the Departments of Education and Labor could affect the preparedness of the U.S. workforce for emerging nanotechnology jobs. Some nanotechnology R&D agencies may also have non-R&D missions related to nanotechnology. For example, EPA conducts and funds R&D but also has a regulatory mission that could affect nanotechnology research, development, production, use, and/or disposal.

[36] U.S. Congress. 2003. 21st Century Nanotechnology Research and Development Act. P.L. 108-153. 15 U.S.C. 7501. 108 Cong., December 3.

[37] Ibid.

[38] FY2003 funding attributed to DHS for the purpose of this calculation is based on nanotechnology R&D appropriations received by the Department of Transportation's Transportation Security Administration (TSA). TSA was transferred to DHS in the Homeland Security Act of 2002 (P.L. 107-296) which was enacted after the start of FY2003.

Key provisions of the act include:

- authorizing appropriations for the nanotechnology-related activities of the National Science Foundation, Department of Energy, NASA, National Institute of Standards and Technology, and Environmental Protection Agency for fiscal years 2005 through 2008, totaling $3.679 billion for the four year period;
- establishing a National Nanotechnology Coordination Office, with a director and full time staff to provide administrative support to the NSTC;
- establishing a National Nanotechnology Advisory Panel (NNAP) to advise the President and the NSTC on matters relating to the NNP.
- establishing a triennial review of the NNP by the National Research Council of the National Academies of Sciences;
- directing the NSTC to oversee the planning, management, and coordination of the program, including the development of a triennial strategic plan;
- directing the Department of Commerce's National Institute of Standards and Technology to establish a program to conduct basic research on issues related to the development and manufacture of nanotechnology, and to use the Manufacturing Extension Partnership program to ensure results reach small- and medium-sized manufacturing companies;
- directing the Secretary of Commerce to use the National Technical Information Service to establish a clearinghouse of information related to commercialization of nanotechnology research;
- directing the Secretary of Energy to establish a program to support consortia to conduct interdisciplinary nanotechnology R&D designed to integrate newly developed nanotechnology and microfluidic tools with systems biology and molecular imaging;
- directing the Secretary of Energy to carry out projects to develop, plan, construct, acquire, operate, or support special equipment, instrumentation, or facilities for investigators conducting nanotechnology R&D; and
- directing the establishment of two centers, on a merit-reviewed and competitive basis: (1) the American Nanotechnology Preparedness Center, to conduct, coordinate, collect, and disseminate studies on the societal, ethical, environmental, educational, legal, and workforce implications of nanotechnology; and to identify anticipated issues related to the responsible research, development, and application of nanotechnology, as well as provide

> recommendations for preventing or addressing such issues, and (2) the Center for Nanomaterials Manufacturing, to encourage, conduct, coordinate, commission, collect, and disseminate research on new manufacturing technologies for materials, devices, and systems with new combinations of characteristics, such as, but not limited to, strength, toughness, density, conductivity, flame resistance, and membrane separation characteristics; and to develop mechanisms to transfer such manufacturing technologies to U.S. industries.

While the act establishes a National Nanotechnology Program, the Executive Branch continues its broader effort under the NNI framework and name. According to the NNI's 2004 Strategic Plan:

> Many of the activities outlined in the Act were already in progress as part of the NNI. Moreover, the ongoing management of the initiative involves considerable input from Federal agencies that are not named specifically in the Act.... For continuity, and to capture this broader participation, the coordinated Federal activities as a whole will continue to be referred to as the National Nanotechnology Initiative.[39]

Structure

Nanoscale Science, Engineering, and Technology Subcommittee. The NNI is coordinated within the White House through the NSTC, the Cabinet-level council by which the President coordinates science, space, and technology policies across the federal government. Operationally, NNI coordination is accomplished through the Nanoscale Science, Engineering, and Technology (NSET) subcommittee of the NSTC's Committee on Technology (CT). The NSET subcommittee also has an informal reporting relationship to the NSTC's Committee on Science (CS). The NSET subcommittee is led by an agency co-chair, currently from the Department of Energy (DOE), and an OSTP co-chair. The NSET subcommittee is comprised of representatives from 25 federal entities, OSTP and the Office of Management and Budget.[40]

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[39] *The National Nanotechnology Initiative Strategic Plan*, Nanoscale Science, Engineering, and Technology Subcommittee, National Science and Technology Council, The White House, December 2004.

[40] The agencies that participate in the NSET subcommittee comprise the NNI. NSET subcommittee members include Bureau of Industry and Security, Department of Commerce; Consumer Product Safety Commission; Cooperative State Research, Education, and Extension Service, Department of Agriculture; Department of Defense; Department of Education; Department of Energy; Department of Homeland Security; Department of Justice; Department of Labor; Department of State; Department of Transportation; Department of the Treasury; Environmental Protection Agency; Food and Drug Administration; Forest Service, Department of Agriculture; Intelligence Technology Innovation Center; International Trade Commission; National Aeronautics and Space Administration; National Institutes of Health, U.S. Department of Health and Human Services; National Institute for Occupational Safety and Health, Center for Disease Control,

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The NSET subcommittee has established several chartered and non-chartered working groups that conduct work in key subject areas. The three chartered working groups are:[41]

National Environmental and Health Implications (NEHI). The NEHI working group was chartered to provide for exchange of information among agencies that support research and those responsible for regulations and guidelines related to nanotechnology products; to facilitate identification, prioritization, and implementation of research and other activities required for the responsible research, development, utilization, and oversight of nanotechnology; and to promote communication of information related to research on environmental and health implications of nanotechnology to other government agencies and non-government parties. To this end, the NEHI working group has been attempting to identify and prioritize environmental, health, and safety research needs related to nanotechnology. Twenty of the 25 NNI agencies participate in the NEHI working group, and 13 agencies fund safety-related nanotechnology research and/or have regulatory authorities to guide the safe use of nanomaterials.[42]

National Innovation and Liaison with Industry (NILI). The NILI working group was chartered to enhance collaboration and information sharing between U.S. industry and government on nanotechnology-related activities. It also facilitates federal, regional, state, and local nanotechnology R&D and commercialization activities. In addition, the NILI working group is to create innovative methods for transferring federally funded technology to industry. The NILI working group has facilitated collaborations between the NNI and the semiconductor/electronics industry, chemical industry, forest products industry, and the Industrial Research Institute.[43]

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[40] (...continued)
Department of Health and Human Services; National Institute of Standards and Technology, Department of Commerce; National Science Foundation; Nuclear Regulatory Commission; U.S. Geological Survey; and the U.S. Patent and Trademark Office, Department of Commerce. The Department of Commerce's Technology Administration was a participating agency in the NNI until its elimination in August 2007 under the America COMPETES Act (P.L. 110-69).

[41] *The National Nanotechnology Initiative: Research and Development Leading to a Revolution in Technology and Industry-Supplement to the President's FY2008 Budget*, Nanoscale Science, Engineering, and Technology Subcommittee, National Science and Technology Council, The White House, July 2007.

[42] Testimony of E. Clayton Teague, Director, National Nanotechnology Coordinating Office, *Research on Environmental and Safety Impacts of Nanotechnology: Current Status of Planning and Implementation under the National Nanotechnology Initiative*, hearing, Subcommittee on Research and Science Education, House Committee on Science and Technology, October 31, 2007.

[43] The Industrial Research Institute is an association of companies and federally funded laboratories with the mission of improving R&D capabilities through the development and dissemination of best practices.

Global Issues in Nanotechnology (GIN). The GIN working group was chartered to monitor foreign nanotechnology programs and development; broaden international collaboration on nanotechnology R&D, including safeguarding the environment and human health; and promote U.S. commercial and trade interests in nanotechnology. The NEHI working group works with the GIN working group to coordinate the U.S. position and participation in international activities related to environmental, health, and safety implications of nanotechnology. The GIN working group facilitates international collaboration on pre-competitive and non-competitive aspects of nanotechnology, and international engagement on trade, commercialization and regulatory issues.

In addition to the chartered working groups, the NSET subcommittee has two non-chartered working groups: the Nanomanufacturing working group and the Nanotechnology Public Engagement and Communications (NPEC) working group.

National Nanotechnology Coordination Office. The National Nanotechnology Coordination Office (NNCO) provides administrative and technical support to the NSET subcommittee. Initially established in 2001 through a memorandum of understanding among the NNI participating agencies,[44] the NNCO was authorized by the 21st Century Nanotechnology Research and Development Act of 2003 (P.L. 108-153). The NNCO was charged under the act with providing technical and administrative support to the NSTC and NNAP; serving as the point of contact for information on Federal nanotechnology activities for the exchange of technical and programmatic information among stakeholders; conducting public outreach; and promoting access to and early application of NNP technologies, innovation, and expertise.

The act authorizes the work of the NNCO to be funded by contributions from NSET subcommittee member agencies. According to the NNCO, funding is provided through a memorandum of understanding signed by eight NNI agencies.[45] In principle, each agency contributes to the NNCO budget in proportion to their share of the President's total nanotechnology budget request for the signatory agencies. However, two of the signatories, EPA and DOT, had sufficiently small enough nanotechnology budgets in the early years of the NNI that they were not expected to contribute. EPA now contributes to funding the NNCO. Total NNCO funding from the agencies in FY2008 is $2.1 million.

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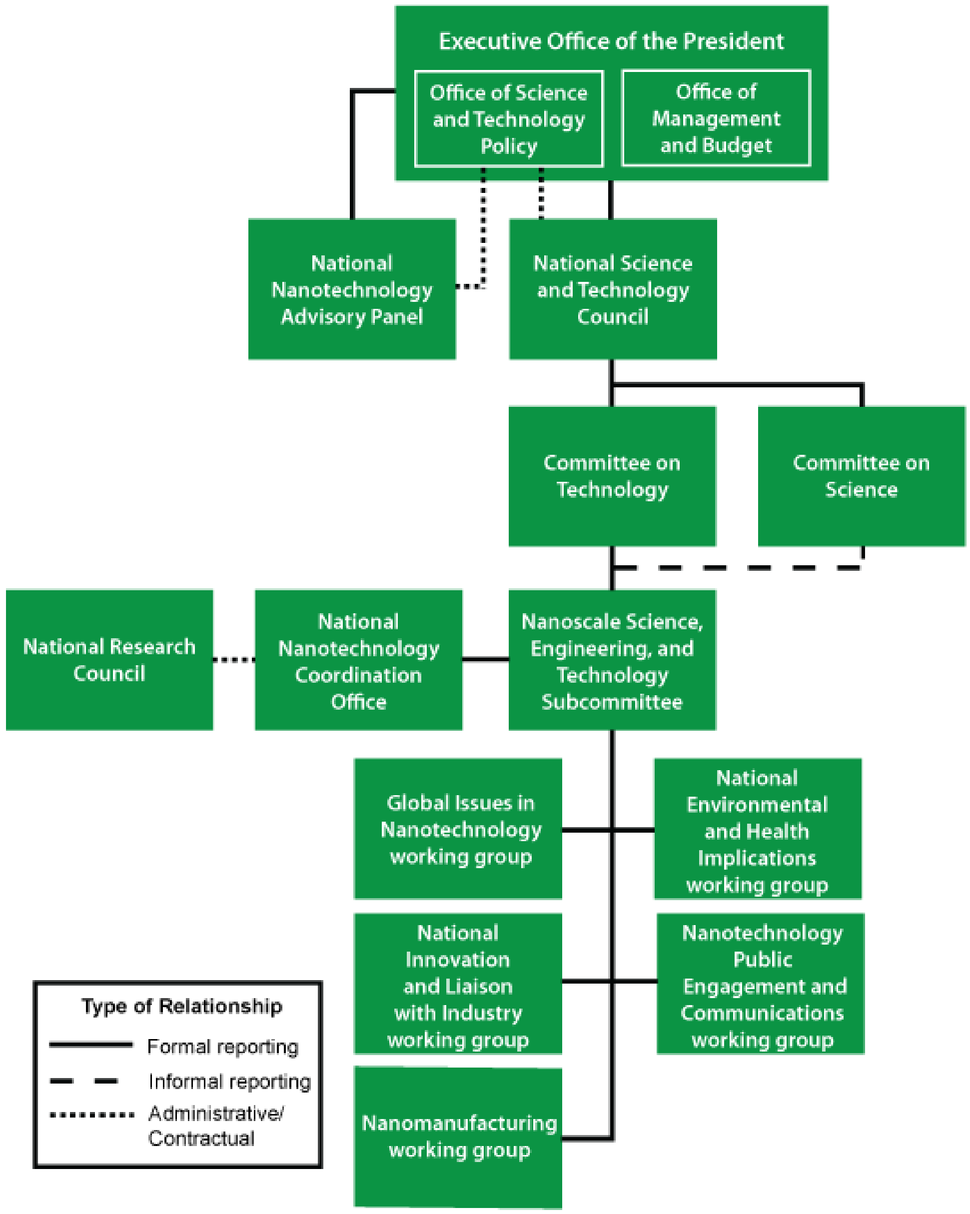
[44] National Nanotechnology Initiative website, [http://www.nano.gov].

[45] The eight agencies that are signatories to the memorandum of understanding are NSF, DOD, DOE, NIH, NIST, NASA, EPA, and DOT.

Figure 1. Organizations With a Role in the National Nanotechnology Initiative and Their Relationships



Source: *The National Nanotechnology Strategic Plan*, Nanoscale, Science, Engineering, and Technology Subcommittee, National Science and Technology Council, The White House, December 2007. (Nanomanufacturing working group added to chart in cited source.)

Funding

The NNI supports fundamental and applied research on nanotechnology by funding research, creating multidisciplinary centers of excellence, and developing key research infrastructure. It also supports activities aimed at addressing the societal implications of nanotechnology, including ethical, legal, human and environmental health, and workforce issues.

This section provides information on NNI funding from two perspectives: organizationally by agency and functionally by program component area.

Agency Funding. The NNI budget is an aggregation of the nanotechnology components of the individual budgets of NNI-participating agencies. The NNI budget is not a single, centralized source of funds that is allocated to individual agencies. In fact, agency nanotechnology budgets are developed internally as part of each agency's overall budget development process. These budgets are subjected to review, revision, and approval by the Office of Management and Budget and become part of the President's annual budget submission to Congress. The NNI budget is then calculated by aggregating the nanotechnology components of the appropriations provided by Congress to each federal agency.

For FY2008, the NNI budget totaled an estimated $1.491 billion, a 4.8% increase over FY2007 funding and more than triple the $464 million federal investment in nanotechnology research in 2001. This growth in nanotechnology R&D investments reflects expectations in Congress and in the executive branch that the NNI will expand fundamental knowledge and make important contributions to national priorities. In his FY2009 budget, the President has requested $1.527 billion for nanotechnology R&D, a 2.3% increase above the estimated FY2008 funding level. The chronology of NNI funding is detailed in **Table 1**.

The President's proposed FY2009 NNI budget supports a broad range of programs among 13 agencies. Agencies with the largest budgets are:

- NSF, which supports fundamental nanotechnology research across science and engineering disciplines;
- DOD, whose investments in nanotechnology are aimed at addressing the department's national security mission;
- DOE, which supports nanotechnology research providing a basis for new and improved energy efficiency, production, storage, and transmission technologies;
- NIH, which emphasizes nanotechnology-based biomedical advances occurring at the intersection of biology and the physical sciences; and
- NIST, which focuses on research in instrumentation, measurement, standards, characterization, and nanomanufacturing.

Other agencies investing in mission-related nanotechnology R&D are NASA, EPA, the Cooperative State Research, Education, and Extension Service (CSREES) and Forest Service at the Department of Agriculture (USDA), National Institute of Occupational Safety and Health (NIOSH), DHS, Department of Justice (DOJ), and Department of Transportation's (DOT's) Federal Highway Administration (FHWA).

Table 1. NNI Funding, by Agency: FY2001-FY2008 and FY2009 Request

(in millions of current dollars)

Agency	FY 2001 Actual	FY 2002 Actual	FY 2003 Actual	FY 2004 Actual	FY 2005 Actual	FY 2006 Actual	FY 2007 Actual	FY 2008 Estimate	FY 2009 Request
NSF	150	204	221	256	335	360	389	389	397
DOD[a]	125	224	322	291	352	424	450	487	431
DOE	88	89	134	202	208	231	236	251	311
NIH (DHHS)	40	59	78	106	165	192	215	226	226
NIST (DOC)	33	77	64	77	79	78	88	89	110
NASA	22	35	36	47	45	50	20	18	19
EPA	5	6	5	5	7	5	8	10	15
DOJ	1	1	1	2	2	<1	2	2	2
DHS		2	1	1	1	2	2	1	1
CSREES (USDA)			1	2	3	4	4	6	3
NIOSH					3	4	7	6	6
Forest Service (USDA)						2	3	5	5
FHWA (DOT)						1	1	1	1
TOTAL[b]	464	697	863	989	1,200	1,351	1,425	1,491	1,527

Sources: *The National Nanotechnology Initiative: Research and Development Leading to a Revolution in Technology and Industry, Supplement to the President's FY2008 Budget*, Nanoscale Science, Engineering, and Technology Subcommittee, National Science and Technology Council, The White House, July 2007. *The National Nanotechnology Initiative Strategic Plan*, Nanoscale Science, Engineering, and Technology Subcommittee, National Science and Technology Council, The White House, December 2004. *National Nanotechnology Initiative: FY2009 Budget & Highlights*, National Science and Technology Council, The White House, February 2008.

a. According to NSTC, the Department of Defense budgets shown above for FY2006 and FY2007 include Congressionally directed funding of approximately $76 million and $63 million, respectively. According to NSTC, the 2008 DOD estimate "includes many earmarks that are outside the NNI plan."

b. Numbers may not add due to rounding of agency budget figures.

Program Component Area Funding. The 21st Century Nanotechnology R&D Act of 2003 called for the NSET subcommittee to develop categories of investment called Program Component Areas (PCA) to provide a means by which Congress and the executive branch can be informed of and direct the relative investments in these areas. The PCAs are categories of investments that cut across the needs and interests of individual agencies and contribute to the achievement of one or more of the NNI's goals. The 2004 NNI strategic plan identified seven PCAs. The 2007 NNI strategic plan splits the seventh PCA, Societal Dimensions, into two PCAs: Environment, Health, and Safety; and Education and Societal Dimensions. A description of the seven initial PCAs and their current funding are provided below,[46] as well as a description of the two derivative PCAs.[47] The chronology of NNI funding by PCA is detailed in **Table 2**.

Table 2. NNI Funding, by Program Component Area, FY2006-FY2009
(in millions of current dollars)

PCA	FY2006 Actual	FY2007 Actual	FY2008 Estimate	FY2009 Request
Fundamental Phenomena and Processes	455.9	480.6	531.6	550.8
Nanomaterials	265.1	258.3	254.7	227.2
Nanoscale Devices and Systems	319.6	344.7	342.3	327.0
Instrumentation Research, Metrology, and Standards	51.0	52.5	60.4	81.5
Nanomanufacturing	33.8	48.1	50.2	62.1
Major Research Facilities and Instrumentation Acquisition	152.4	152.4	154.4	161.3
Societal Dimensions	73.5			
- Environment, Health, and Safety		48.3	58.6	76.4
- Education and Societal Dimensions		39.2	39.0	40.7
TOTAL	**1,351.2**	**1,424.1**	**1,491.2**	**1,527.0**

Source: *The National Nanotechnology Initiative: Research and Development Leading to a Revolution in Technology and Industry, Supplement to the President's FY2008 Budget*, Nanoscale Science, Engineering, and Technology Subcommittee, National Science and Technology Council, The White House, July 2007.

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[46] *The National Nanotechnology Initiative Strategic Plan*, Nanoscale Science, Engineering, and Technology Subcommittee, National Science and Technology Council, The White House, December 2004.

[47] *The National Nanotechnology Initiative Strategic Plan*, Nanoscale Science, Engineering, and Technology Subcommittee, National Science and Technology Council, The White House, December 2007.

Fundamental Phenomena and Processes. Fundamental Phenomena and Processes includes investments in the discovery and development of fundamental knowledge pertaining to the new phenomena in the physical, biological, and engineering sciences that occur at the nanoscale, as well as in understanding and articulation of scientific and engineering principles related to nanoscale structures, processes, and mechanisms.

FY2008 funding for Fundamental Phenomena and Processes rose to $531.6 million, up $51.0 million (10.6%) over the FY2007 level due to increases in DOD (up $48.6 million, 23.1%) and NIH (up $9.9 million, 21.7%) funding in this PCA. The increases in FY2008 funding for DOD and NIH in this PCA were partially offset by decreases in other agencies' budgets. The President's FY2009 budget proposes $550.8 million in funding for this PCA, up $19.2 million (3.6%) above the FY2008 level.[48]

Nanomaterials. Nanomaterials includes research investments to discover novel nanoscale and nanostructured materials. This PCA also attempts to understand the properties of nanomaterials, and supports R&D to enable the design and synthesis, in a controlled manner, of nanoscale materials with targeted properties.

FY2008 funding for Nanomaterials fell to $254.7 million, down $3.6 million (1.4%) from the FY2007 level, led by a decrease in DOD funding in this PCA (down $17.1 million, 19.9%). The decline in FY2008 spending in this PCA resulting from the DOD reduction was partially offset by increases in other agencies' budgets, including a $9.0 million (13.1%) increase in DOE funding and a $3.7 million (6.3%) increase in NSF funding. The President's FY2009 budget proposes $227.2 million for this PCA, a decrease of $27.5 million (10.8%) from the FY2008 level.[49]

Nanoscale Devices and Systems. Nanoscale Devices and Systems include R&D investments that apply nanoscale science and engineering principles to create novel devices and systems or to improve existing ones. It also includes the use of nanoscale or nanostructured materials to achieve improved performance or new functionality. To meet this definition, the enabling science and technology must be at the nanoscale, but the systems and devices are not restricted to that size.

Funding for Nanoscale Devices and Systems fell to $342.3 million in FY2008, down $2.4 million (0.7%) from the FY2007 level. The President's FY2009 budget proposes $327.0 million in funding for this PCA, a decrease of $15.3 million (4.5%) from the FY2008 level, largely due to reductions in DOD (down $12.1 million, 10.1%) and DOE (down $4.9 million, 37.7%) funding in this PCA. The decrease in

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[48] *The National Nanotechnology Initiative: FY2009 Budget & Highlights*, Nanoscale Science, Engineering, and Technology Subcommittee, National Science and Technology Council, The White House, February 2008.

[49] Ibid.

DOD and DOE funding for this PCA is somewhat offset by increases in other agencies' budgets.[50]

Instrumentation Research, Metrology, and Standards. The Instrumentation Research, Metrology, and Standards PCA includes R&D investments for development of tools needed to advance nanotechnology research and commercialization. Instrumentation for characterization, measurement, synthesis, and design of nanotechnology materials, structures, devices, and systems is funded through this PCA. R&D and other activities related to development of standards, including standards for nomenclature, materials, characterization, testing, and manufacture are also in this PCA.

FY2008 funding for Instrumentation Research, Metrology, and Standards increased to $60.4 million, up $7.9 million (15.0%) over the FY2007 level, led by a $3.7 million (86.0%) increase in DOD funding. The President's FY2009 budget proposes $81.5 million in funding for this PCA, an increase of $21.1 million (34.9%) above the FY2008 level, with DOE and NIST accounting for the largest increases.[51]

Nanomanufacturing. Nanomanufacturing R&D supports the development of scalable, reliable, cost-effective manufacturing of nanoscale materials, structures, devices, and systems. It also includes R&D and integration of ultra-miniaturized top-down processes and complex bottom-up processes.[52]

FY2008 funding for Nanomanufacturing rose to $50.2 million, up $2.1 million (4.4%) over the FY2007 level due to increases in the budgets of NIST and DOE. The President's FY2009 budget proposes $62.1 million for this PCA, an increase in funding of $11.9 million (23.7%) above the FY2008 level, due to increases in DOD, DOE, and NIST funding for this PCA.[53]

Major Research Facilities and Instrumentation Acquisition. This PCA includes investments in the establishment and ongoing operations of user facilities and networks, the acquisition of major instrumentation, and other activities related to infrastructure for the conduct of nanoscale science, engineering, and technology R&D.

FY2008 funding for Major Research Facilities and Instrumentation Acquisition rose to $154.4 million, an increase of $2.0 million (1.3%) over the FY2007 level. The President's FY2009 budget proposes $161.3 million for this PCA, an increase

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[50] Ibid.

[51] Ibid.

[52] Top-down processes are those that achieve design features by removing material from a larger block of material; bottom-up processes begin with smaller building blocks (atoms or molecules) and achieve design features by putting them together, possibly using self-assembly.

[53] *The National Nanotechnology Initiative: FY2009 Budget & Highlights*, Nanoscale Science, Engineering, and Technology Subcommittee, National Science and Technology Council, The White House, February 2008.

of $6.9 million (4.5%) above the FY2008 level, led by a $9.2 million (10.0%) increase in DOE funding and partially offset by decreases in other agencies' budgets.[54]

Societal Dimensions. The Societal Dimensions PCA includes investments in research and other activities that address the broad implications of nanotechnology to society. This includes assessing benefits and risks through research directed at environmental, health, and safety impacts of nanotechnology development; risk assessment of such impacts; education-related activities, such as development of materials for schools, undergraduate programs, technical training, and public outreach; and research directed at identifying and quantifying the broad implications of nanotechnology for society, including social, economic, workforce, educational, ethical, and legal implications.

Under the 2007 NNI Strategic Plan, the Societal Dimensions PCA was divided into two separate PCAs: Environment, Health, and Safety, and Education and Societal Dimensions. Future PCA reporting will use the new eight PCA taxonomy. NSTC has retroactively reported FY2007 Societal Dimensions PCA spending in the new PCAs.[55] The NSET subcommittee characterizes the new PCAs as follows:[56]

Environment, Health, and Safety. This PCA addresses research primarily directed at understanding the environmental, health, and safety impacts of nanotechnology development and corresponding risk assessment, risk management, and methods for risk mitigation.

FY2008 funding for Environment, Health, and Safety rose to $58.6 million, up $10.3 million (21.3%) above the FY2007 level. A total of nine agencies funded work in this PCA in FY2008, including three agencies that did not have funding in this PCA in FY2008.[57] The President's FY2009 budget proposes $76.4 million in funding for this PCA, an increase of $17.8 million (30.4%) above the FY2008 level, led by increases at NIST (up $12 million) and EPA (up $4.7 million).[58]

Education and Societal Dimensions. This PCA addresses education-related activities such as development of materials for schools, undergraduate programs, technical training, and public communication, including outreach and

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[54] Ibid.

[55] *The National Nanotechnology Initiative: FY2009 Budget & Highlights*, Nanoscale Science, Engineering, and Technology Subcommittee, National Science and Technology Council, The White House, February 2008.

[56] *The National Nanotechnology Initiative Strategic Plan*, Nanoscale Science, Engineering, and Technology Subcommittee, National Science and Technology Council, The White House, December 2004.

[57] The three agencies reporting FY2008 funding in the Environment, Health, and Safety PCA that reported no funding for this PCA in FY2007 are DOD, DOE, and NASA.

[58] *The National Nanotechnology Initiative: FY2009 Budget & Highlights*, Nanoscale Science, Engineering, and Technology Subcommittee, National Science and Technology Council, The White House, February 2008.

engagement. Such activities include research directed at identifying and quantifying the broad implications of nanotechnology society, including social, economic, workforce, educational, ethical, and legal implications.

FY2008 funding for Education and Societal Dimensions fell slightly to $39 million, down $0.2 million (less than 1%) from the FY2007 level. The President's FY2009 budget proposes $40.7 million in funding for this PCA, an increase of $1.7 million (4.4%) above the FY2008 level, accounted for entirely by an increase in NSF funding.

Centers, Networks, and User Facilities

A key facet of the National Nanotechnology Initiative has been the development of an extensive infrastructure of interdisciplinary research and education centers, networks, and user facilities. The centers and user facilities are located at universities and federal laboratories across the country.

Centers and networks provide opportunities and support for multidisciplinary research among investigators from a variety of disciplines and research sectors, including academia, industry, and government laboratories. Such multidisciplinary research not only can lead to advances in knowledge, but also may foster relationships that further the development of basic research results into devices and other applications.

Many agencies support such centers. Examples of federal and federally supported centers include:

- The National Science Foundation has established university-based centers focused exclusively on nanotechnology, including 15 Nanoscale Science and Engineering Centers (NSEC), one Engineering Research Center, one Science and Technology Center, four Materials Research Science and Engineering Centers, two Nanoscale Science and Engineering Education Centers, and five Nanoscale Science and Engineering Networks.[59]

- The NIH has established more than 20 centers, including eight university-based Nanomedicine Development Centers; a Nanotechnology Characterization Laboratory, established by the National Cancer Institute (NCI), in partnership with NIST and the Food and Drug Administration; eight university-based Centers of Cancer Nanotechnology Excellence, established under the NCI's Alliance for Nanotechnology in Cancer initiative; and four university-based centers, established by the National Heart, Lung, and Blood Institute under its Program of Excellence in Nanotechnology.

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[59] In addition, 18 other Materials Research Science and Engineering Centers conduct nanotechnology-related research as part of their overall efforts.

- The Department of Defense supports two university-based nanotechnology research centers, as well as the Institute for Nanoscience at the Naval Research Laboratory.
- NASA has established three centers under its University Research, Engineering, and Technology Institute program.
- The Department of Energy has established five Nanoscale Science Research Centers (NSRCs) co-located with its national labs.
- NIST has established a Center for Nanoscale Science and Technology (CNST).
- NIOSH has established a Nanotechnology Research Center to conduct research into the application of nanoparticles and nanomaterials in occupational safety and health and the implications of nanoparticles and nanomaterials for work-related injury and illness.

Many of the centers are designated as user facilities and are available to researchers not located at the center. User facilities are designed to allow outside researchers to take advantage of facilities, equipment, tools, and expertise. These shared resources provide researchers the opportunity to conduct research, characterize materials, and test products using equipment and facilities that their individual companies, universities, or organizations could not afford to acquire, support, or maintain. Conditions for user access vary by facility and agency. In general, users are not charged for pre-competitive, non-proprietary work leading to publication, and are charged on a cost-recovery basis for proprietary work. In some cases, the user facilities are located at federal government laboratories (e.g. the Department of Energy's five NSRCs, and the NIST CNST); other user facilities are located at universities and supported with federal funds (e.g. NSF's 13 university-based centers in the National Nanotechnology Infrastructure Network (NNIN)).

As mentioned earlier, the 21st Century Nanotechnology R&D Act of 2003 directed the establishment of two centers, the American Nanotechnology Preparedness Center and the Center for Nanomaterials Manufacturing. According to the NSET subcommittee, the requirement to establish the American Nanotechnology Preparedness Center was met by NSF's establishment of the Network for Nanotechnology in Society, comprised of centers at the University of California, Santa Barbara (with the participation of Harvard University and the University of South Carolina) and the University of Arizona.[60] These centers were funded under NSF's Nanoscale Science and Engineering Center (NSEC) program and did not include participation by any other NSET subcommittee agency.[61] The NSET subcommittee states that the requirement for establishing the Center for Nanomaterials Manufacturing was met by NSF's establishment of a National

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[60] Private telephone communication between CRS and NSTC staff, January 31, 2008.

[61] Private email communication between CRS and NSF staff, January 31, 2008.

Nanomanufacturing Network (NNN) comprised of four NSECs. The Center for Integrated Hierarchical Manufacturing at the University of Massachusetts Amherst is the main node of the NNN.[62] The NNN NSECs were established by NSF in collaboration with DOD and NIST, but exclusively with NSF funds.[63]

NNI Reports and Assessments

This section presents summaries of recent reports from the NSTC's Nanoscale Science, Engineering, and Technology Subcommittee and assessments conducted by the National Research Council and the President's Council of Advisors on Science and Technology.

NNI Reports

The NNI's coordinating body, the NSTC's Nanoscale Science, Engineering, and Technology Subcommittee, produces a variety of reports that serve to inform Congress and other key stakeholders on the initiatives' current activities, investments, and priorities.

The National Nanotechnology Strategic Plan (2007).[64] The 21st Century Nanotechnology R&D Act of 2003 (P.L. 108-153) requires the NSTC to develop an NNI strategic plan every three years. This plan is to guide the program's activities to meet the goals, priorities, and anticipated outcomes of the participating agencies. In addition, the act requires the triennial report to address how the program intends to move results out of the laboratory and into application for the benefit of society, its plan for long-term funding for interdisciplinary R&D, and the allocation of funding for interagency projects. The 2007 strategic plan is the first to follow external assessments by the National Academies and PCAST (operating as the NNAP) and seeks to incorporate the findings of these reviews. Of particular note:

- The 2007 *National Nanotechnology Initiative Strategic Plan* includes a new chapter on "High-Impact Application Opportunities and Critical Research Needs" possibly indicating an effort on the part of the Administration to move the NNI toward more directed research with commercial and societal benefits. Much of the early NNI work has been focused on basic research and mechanisms by which such research may produce economic and societal dividends. Seven years into the NNI, the program is under increasing scrutiny to deliver the promised benefits. While the plan does not establish R&D or application targets per se, this chapter illustrates tangible benefits that may be achieved by research supported under the NNI.

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[62] Private telephone communication between CRS and NSTC staff, January 31, 2008.

[63] Private e-mail communication between CRS and NSF staff, January 31, 2008.

[64] *The National Nanotechnology Strategic Plan*, Nanoscale, Science, Engineering, and Technology Subcommittee, National Science and Technology Council, The White House, December 2007.

In addition, the plan provides a matrix that identifies which agencies have a central or supporting role in each key application area. The plan also provides a series of nanotechnology application-specific vignettes on topics such as early detection of life-threatening disease, smarter computers, more energy-efficient transportation, and energy security.

- The 2007 *National Nanotechnology Initiative Strategic Plan* split the Societal Dimensions PCA into two separate PCAs: Environmental, Health, and Safety, and Education and Societal Dimensions. This change responds to increased Congressional and public attention to EHS needs. Some critics of the NNI had raised concerns that the inclusion of investments in education and other societal dimensions in the broader category obscured and artificially inflated the perception of investments in EHS R&D.

- The plan also identifies four areas of common interest across agencies that is to be the focus of future workshops: sensors and nanoelectronics, energy, fate and transport of nanomaterials, and medical and health applications.

The National Nanotechnology Initiative: Research and Development Leading to a Revolution in Technology and Industry, Supplement to the President's FY2008 Budget.[65] Each year the NSET subcommittee publishes a supplement to the President's annual budget request. The FY2008 NNI budget supplement provides a more detailed look at each agency's nanotechnology R&D budget request and a break-out of the prior, current, and requested year budgets for each PCA. In addition, the report provides data on agency funding for Small Business Innovation Research (SBIR) and Small Business Technology Transfer Research (STTR). The report describes proposed changes in agency R&D budgets, as well as in the balance of investments by PCA. Of particular note:

- The President's FY2008 budget proposed a $90.9 million (6.7%) increase in the overall NNI budget.

- Funding for EHS R&D in FY2007 rose to $47.8 million, a 26.8% increase over FY2006. The President's FY2008 request includes 58.6 million, a 22.6% increase over estimate FY2007 funding.

- The President's FY2008 budget request reflected a decline in spending on nanoscale devices and systems of $41.7 million (13.1%) below FY2007, led by a decline in DOD spending of $36.9 million (34.3%).

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[65] *The National Nanotechnology Initiative: Research and Development Leading to a Revolution in Technology and Industry, Supplement to the President's FY2008 Budget*, Nanoscale, Science, Engineering, and Technology Subcommittee, National Science and Technology Council, The White House, July 2007.

The National Nanotechnology Initiative: Environmental, Health, and Safety Research Needs for Engineered Nanoscale Materials.[66] This report documents the efforts of the NSET subcommittee's Nanotechnology Environmental and Health Implications (NEHI) working group to identify, prioritize, and implement research and other activities required for the responsible research and development of nanotechnology. The report is designed to help inform the research, risk assessment, and risk management activities of federal agencies and the private sector.

The report identifies priority research within five general research areas: instrumentation, metrology, and analytical methods; nanomaterials and human health; nanomaterials and the environment; health and environmental surveillance; and risk management methods.

The report identifies several next steps:

- prioritize research needs among those identified in the report;
- evaluate in greater detail the current NNI EHS research portfolio;
- perform a "gap analysis" of the NNI EHS research compared to the prioritized needs;
- coordinate and facilitate among the NNI agencies' research programs to address priorities; and
- establish a process for periodic review of progress and for updating research needs and priorities.

The report concludes that conducting EHS research in parallel with the development of nanomaterials and their applications will help to ensure the full, safe, and responsible realization of the promise of nanotechnology, and that coordination of research activities among NNI-participating agencies, as well as with industry and other governments, is necessary to expedite progress. In contrast, some NGOs have asserted the need for EHS research to precede the development of nanomaterials and nanotechnology applications.

Prioritization of Environmental, Health, and Safety Research Needs for Engineered Nanoscale Materials: An Interim Document for Public Comment.[67] This document is a follow-on to the *Environmental, Health, and Safety Research Needs for Engineered Nanoscale Materials* report (discussed above),

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[66] *The National Nanotechnology Initiative: Environmental, Health, and Safety Research Needs for Engineered Nanoscale Materials*, Nanoscale, Science, Engineering, and Technology Subcommittee, National Science and Technology Council, The White House, September 2006.

[67] *Prioritization of Environmental, Health, and Safety Research Needs for Engineered Nanoscale Materials: An Interim Document for Public Comment*, Nanoscale, Science, Engineering, and Technology Subcommittee, National Science and Technology Council, The White House, August 2007.

incorporating public comments, refinements of the prioritization principles, and continued assessment of research needs. This report further identifies and defines five priorities within each of the five general categories of research needs established in the earlier document and presents the revised principles and the process used for this prioritization. The NEHI working group of the NSET subcommittee expects to use this report to evaluate the NNI's current EHS research portfolio, perform a gap analysis, and identify opportunities for interagency collaboration. The report stresses that the NSET subcommittee is "pursuing a dynamic, open, and transparent process in developing an NNI EHS research strategy" and invites continuing public input.

NNI Assessments

The 21st Century Nanotechnology R&D Act of 2003 (P.L. 108-153) requires periodic external reviews of the National Nanotechnology Program (NNP) by the National Research Council, an arm of the National Academies,[68] and the National Nanotechnology Advisory Panel.[69] In their first reviews, both institutions reviewed the NNI in its entirety, including the activities of those agencies that are not part of the NNP.

In general, these reviews concluded that the NNI has been successful so far and that its efforts are important to future U.S. technological leadership and commercial competitiveness. Both reports emphasize that much nanotechnology research is still in its very early stages and caution against expecting too much in the near term from this nascent technology. The reports also laud the cooperative efforts between the NNI and stakeholders in academia and industry and encourage increased interactions with industry, state and local economic developers, and, where appropriate, international partners.

A Matter of Size: Triennial Review of the National Nanotechnology Initiative.[70] This 2006 report presents the findings of the National Research Council's (NRC) first triennial review mandated by the 21st Century Nanotechnology R&D Act of 2003.

The NRC study concluded that the NNI has been successful in coordinating nanoscale efforts and interests across the federal government, in catalyzing cooperative R&D across a variety of scientific and engineering disciplines, and in opening a host of new scientific opportunities through its infrastructure and R&D

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[68] The National Research Council, the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine are part of a private, non-profit institution established under a congressional charter. They are collectively referred to as the National Academies.

[69] P.L. 108-153 directs the President to "establish or designate a National Nanotechnology Advisory Panel." In July 2004, President Bush designated the President's Council of Advisors on Science and Technology to serve as the NNAP by issuing Executive Order 13349, *Amending Executive Order 13226 To Designate the President's Council of Advisors on Science and Technology To Serve as the National Nanotechnology Advisory Panel*.

[70] *A Matter of Size: Triennial Review of the National Nanotechnology Initiative*, National Research Council, 2006.

investments. The NRC attributed much of this success to effective communication and coordination by the NSET subcommittee and the NNCO.

Recommendations. Here are the recommendations made by the NRC followed by a discussion of each.

NRC recommendation:

> the federal government [should] sustain investments in a manner that balances the pursuit of shorter-term goals with support for longer-term R&D and that ensures a robust supporting infrastructure, broadly defined. Supporting long-term research effectively will require making new funds available that do not come at the expense of much-needed ongoing investment in U.S. physical sciences and engineering research.

President Bush has expressed support for increasing federal R&D funding for the physical sciences and engineering, most notably in his American Competitiveness Initiative which includes nanotechnology investments. Yet, as Federal non-discretionary spending growth increases pressure on federal discretionary spending, finding new funds to support long-term nanotechnology research may need to come from other scientific disciplines.

NRC recommendation:

> the federal government [should] establish an independent advisory panel with specific operational expertise in nanoscale science and engineering; management of research centers, facilities, and partnerships; and interdisciplinary collaboration to facilitate cutting-edge research on and effective and responsible development of nanotechnology.

In July 2004, President George W. Bush implemented the provision of the 21st Century Nanotechnology Research and Development Act to "establish or designate a National Nanotechnology Advisory Panel" by issuing Executive Order 13349, which amends Executive Order 13226, designating the President's Council of Advisors on Science and Technology to serve as the NNAP.

The NRC's recommendation suggests that the President's designation of PCAST to serve as the legislatively mandated National Nanotechnology Advisory Panel is not fully adequate. Critics of the use of PCAST to serve as the NNAP maintain that the scope and depth of expertise needed to provide effective guidance on the NNI requires an independent panel of people with nanotechnology- and interdisciplinary-specific expertise and an undivided focus. Supporters of the use of PCAST for this function assert that a single advisory panel provides an integrated perspective, reduces unnecessary cost and management burdens, and that expertise can be added to the panel or accessed through non-member technical advisory groups.

NRC recommendation:

> federal agencies participating in the NNI, in consultation with the NNCO and the Office of Management and Budget, should continue to develop and enhance

> means for consistent tracking and reporting of funds requested, authorized, and expended annually. The current set of PCAs provides an appropriate initial template for such tracking.

It is difficult to assess and track funding for specific purposes within the NNI because the initiative is not centrally funded and operated. The NNI budget is an aggregation of the nanotechnology-related activities of the participating federal agencies. Congress funds the NNI-related R&D on an agency-by-agency basis, with responsibilities crossing many authorizing committees and appropriations subcommittees. Thus, while it is relatively straightforward to quantify an agency's nanotechnology budget, tracking all NNI investments related to a particular activity — EHS-related research, for example — is much more difficult. The PCAs serve to provide such a tracking mechanism. In addition, according to the 2007 *National Nanotechnology Initiative Strategic Plan*, the division of the Societal Dimensions PCA into two PCAs — Environmental, Health, and Safety; and Educational and Societal Dimensions — is intended to better understand and manage the NNI investment. Such a change indicates a level of flexibility that may enable the executive branch and Congress to more effectively manage and balance investments in discrete areas of the NNI.

NRC recommendation:

> the NSET Subcommittee [should] carry out or commission a study on the feasibility of developing metrics to quantify the return to the U.S. economy from the federal investment in nanotechnology R&D. The study should draw on the Department of Commerce's expertise in economic analysis and its existing ability to poll U.S. industry. Among the activities for which metrics should be developed and relevant data collected are technology transfer and commercial development of nanotechnology.

Few efforts have been made within the federal government to understand the economic impacts of the nation's investments in the NNI. Identification and tracking of data that could serve as an indicator of success in commercializing nanotechnology research or the effects on U.S. job creation or retention has not been formalized. To the extent that federal assessments of the economic contribution of and/or potential for nanotechnology products have occurred, they have not been performed with analytical rigor. Although the Commerce Department retains its economic analysis expertise, resident primarily in the Economics and Statistics Administration's Bureau of Economic Analysis, the Department's Technology Administration, which led Commerce's NNI activities and had government-wide responsibilities for technology transfer activities, was eliminated in August 2007.[71] Prior to its elimination, the Technology Administration contracted for two studies that could contribute to addressing this NRC recommendation: an analysis of barriers to nanotechnology commercialization performed by the University of Illinois at Springfield, and an analysis of innovation metrics conducted by the Alliance for Science and Technology

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[71] The Technology Administration was eliminated in the America COMPETES Act (P.L. 110-69).

Research in America (ASTRA). These reports are publicly available at Commerce Department websites.[72]

NRC recommendation:

> research on the environmental, health, and safety effects of nanotechnology [should] be expanded. Assessing the effects of engineered nanomaterials on public health and the environment requires that the research conducted be well-defined and reproducible, and that effective methods be developed and applied to (1) estimate the exposure of humans, wildlife, and other ecological receptors to source material; (2) assess effects on human health and ecosystems of both occupational and environmental exposure; and (3) characterize, assess, and manage the risks associated with exposure.

While the NRC asserts the need for additional EHS research, it does not quantify how much more is needed. Clayton Teague, director of the NNCO, has testified that the current level of investment in EHS research is adequate.[73] Many critics from academia, industry, and non-profit organizations have argued strongly that the NNI needs a greater level of investment in EHS research.[74] These critics argue from a variety of perspectives, including the need to:

- protect workers, human health, and the environment;
- create public faith and confidence in the safety of nanotechnology products;
- prevent a problem with one specific nanotechnology product from resulting in a loss of public support for all nanotechnology R&D; and
- create a predictable and stable regulatory environment.

This last factor is deemed by some as critical to fostering future nanotechnology investments.

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[72] *Barriers to Nanotechnology Commercialization*, College of Business Management, University of Illinois at Springfield, September 2007. [http://www.osec.doc.gov/Report-Barriers%20to%20Nanotechnology%20Commercialization.pdf] *Innovation Vital Signs Project*, Alliance for Science and Technology Research in America, July 2007. [http://www.ntis.gov/ta_reports/Report-InnovationVitalSigns.pdf]

[73] Testimony of Clayton Teague, director of the NNCO, hearing, "Environmental and Safety Impacts of Nanotechnology: What Research is Needed?" House Committee on Science, November 17, 2005. [http://commdocs.house.gov/committees/science/hsy24464.000/hsy24464_0.HTM]

[74] Ibid.

NRC recommendation:

> the NSET Subcommittee [should] create a working group on education and the workforce that engages the Department of Education and Department of Labor as active participants.

The NSET subcommittee has sought, with limited success, greater involvement of the Departments of Education and Labor in the subcommittee's activities. An NSET subcommittee working group on education and the workforce has not yet been established.

With advocates promising the creation of many new jobs — some assert millions — as a result of global nanotechnology investments, some have expressed concern that the country must prepare students for nanotechnology research, engineering, and production jobs.[75] Assessing which industries are likely to create such jobs, which skills will be needed, and in what timeframe are key challenges. If workers with nanotechnology-specific skills are needed and no workers are available domestically (U.S. citizens, resident aliens, or those in the United States on work visas), potential employers may opt to establish or move operations outside the United States to tap workers with those skills abroad. Conversely, if students are trained for jobs that do not emerge or do not emerge in the same timeframe as students are entering the job market, this investment is lost. In addition, potential students may be discouraged from pursuing future nanotechnology-related studies. Close coordination among the Departments of Commerce, Education, and Labor might help to align federal education and training efforts better with the labor market for nanotechnology workers.

The 21st Century Nanotechnology R&D Act also directed the NRC to address two other issues in its first triennial report: Is molecular self assembly feasible for manufacturing of materials and devices at the nanoscale? And, what are the needs for standards, guidelines, or strategies for ensuring the responsible development of nanotechnology?

Molecular Self-Assembly. Self-assembly is the process by which components (atoms, molecules, or more complex structures) form, without external control or direction, an organized structure. For example, water molecules dispersed in air in cold temperatures can self-assemble to form snowflakes. Our bodies act as self-assemblers, producing a variety of cells as needed (e.g. to repair a damage to the skin or produce new blood cells from added nutrients).

To what extent can molecular self-assembly be used as a tool for nanomanufacturing? On this issue, the NRC concluded that molecular self-assembly is feasible for the manufacture of simple materials and devices. However, for the manufacture of more sophisticated materials and devices, including complex objects produced in large quantities, the NRC found it unlikely that simple self-assembly

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[75] Phillip J. Bond, Under Secretary for Technology, U.S. Department of Commerce, remarks, "Nanotechnology: Economic Opportunities, Societal and Ethical Challenges," NanoCommerce 2003, December 9, 2003. [http://www.technology.gov/Speeches/PJB_031209.htm] *Sizing Nanotechnology's Value Chain*, Lux Research, October 2004.

processes will yield the desired results. One major barrier cited is the probability of error during assembly as a result of the systems' complexity.

Standards, Guidelines, and Strategies for Ensuring Responsible Development of Nanotechnology. The NRC concluded that it is not possible yet to make a rigorous assessment of the level of environmental and health risks posed by engineered nanomaterials and called for further development of risk assessment protocols. The NRC report also stated that the need for more EHS data requires an expanded research effort to complement dialog on these issues. In addition, until reproducible and well-characterized EHS data are available to inform the development of rigorous risk-based guidelines and best practices, the NRC found it prudent to recommend use of precautionary measures to protect the health and safety of workers, the public, and the environment. The NRC report also stressed that addressing the ethical and societal impacts of nanotechnology will require an integrated approach among scientists, engineers, social scientists, toxicologists, policymakers, and the public.

The National Nanotechnology Initiative at Five Years: Assessment and Recommendations of the National Nanotechnology Advisory Panel, President's Council of Advisors on Science and Technology.[76] This report presents the findings of the first biennial review of the NNI by the President's Council of Advisors on Science and Technology's, acting as the National Nanotechnology Advisory Panel, as mandated by the 21st Century Nanotechnology R&D Act of 2003. PCAST submitted its first report to the President on May 16, 2005, titled *The National Nanotechnology Initiative at Five Years: Assessment and Recommendations of the National Nanotechnology Advisory Panel*. The second report was due in 2007 but has yet to be completed.

The PCAST report finds that the United States is the acknowledged leader in nanotechnology R&D, but the U.S. leadership position is under increasing competitive pressure from growing public and private investments around the world. The report states that the federal investment in the NNI has been well-spent, the United States is well-positioned to maintain global leadership going forward, and continued robust funding is important for long-term U.S. economic well-being and national security. This assessment of the U.S. leadership position is founded not on sales, growth, or market share of commercial products — common measures of global competitiveness for established products — but rather on metrics that may serve as early indicators of potential innovation, such as the U.S. share of scientific publications and patents. The use of such metrics may not be universally accepted as predictive of leadership position. Technological leadership — or even leadership in innovation — does not ensure that the economic benefits from such leadership will accrue to the United States. Companies may choose to manufacture products or conduct other value-added activities outside the United States. If the assessment of national competitiveness is expanded to include the value-added activities and jobs

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[76] *The National Nanotechnology Initiative at Five Years: Assessment and Recommendations of the National Nanotechnology Advisory Panel*, President's Council of Advisors on Science and Technology, May 2005.

generated or retained within the United States, then the metrics for assessing leadership might change.

The PCAST report acknowledges that there are potential environmental and health risks associated with nanotechnology, but finds that the NNI is directing appropriate attention and adequate resources to the research that will ensure the protection of the public and the environment. Nanotechnology products should not be immune from regulation, according to the report, but such regulation must be rational and based on science, not on perceived fears. The PCAST report states that strong communication exists among the NNI agencies responsible for research and regulation. The PCAST report contains four recommendations for the NNI:

PCAST recommendation:

> To further facilitate technology transfer from the lab to the marketplace, the NNI should expand its interaction with industry, increase federal-state coordination, and improve knowledge management of and access to NNI assets, such as user facilities and instrumentation.

The NSET subcommittee's National Innovation and Liaison with Industry (NILI) working group was established to facilitate NNI interactions with industry, and with state and local nanotechnology initiatives. The NILI working group's limited resources and agency participation have hindered its ability to conduct more extensive and sustained outreach.[77] Due to the structure and resource allocation of the NNI, the initiative's engagements with industry and with state and local initiatives are largely limited to single agency or laboratory interactions and to public engagement activities, such as speeches and information on the NNI website.[78]

PCAST recommendation:

> The NNI should continue its efforts to understand the possible toxicological effects of nanotechnology and where harmful human or environmental effects are proven, pertinent federal agencies should apply appropriate regulatory mechanisms. There should be strong interagency and international collaboration on this issue to eliminate unnecessary duplication of research efforts and to ensure wide dissemination of information. Since exposure to nanomaterials is most likely to occur during the manufacturing process, research on potential hazards associated with workplace exposure must be given the highest priority.

With respect to collaboration on EHS issues, the NSET subcommittee's National Environmental and Health Implications (NEHI) working group is the primary EHS coordination mechanism for participating NNI agencies. The Global Issues in Nanotechnology (GIN) working group works with the NEHI working group on international collaboration on EHS issues. The NIOSH has published several documents addressing concerns about workplace exposure to nanoparticles. *Approaches to Safe Nanotechnology: An Information Exchange With NIOSH* was

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[77] Private telephone and e-mail communication with Sean Murdock, executive director of the NanoBusiness Alliance, February 4, 2008.

[78] Ibid.

intended to provide the best currently available knowledge on nanoparticle toxicity and control and to solicit input from the stakeholder community.[79] *Progress Toward Safe Nanotechnology in the Workplace* details the work of NIOSH's Nanotechnology Research Center from 2004 through 2006.[80] In December 2007, NIOSH released interim guidance concerning the medical screening of workers potentially exposed to engineered nanoparticles during the manufacture and industrial use of nanomaterials. The NIOSH says that the document is intended to "generate discussion, fill the current knowledge gap, and provide interim recommendations until further scientific information becomes available."[81] The NIOSH is currently seeking public comment on this guidance.

With respect to regulatory issues associated with nanotechnology, see CRS Report RL34332, *Engineered Nanoscale Materials and Derivative Products: Regulatory Challenges*, by Linda-Jo Schierow.

PCAST recommendation:

> The NNI should establish relationships with the Department of Education and Department of Labor to develop education and training systems to support the Nation's technical proficiency in areas related to nanotechnology.

The PCAST report's recommendation is similar to the recommendation made by the NRC and is discussed earlier in this paper.

PCAST recommendation:

> The NNI must support research aimed at understanding the societal implications of nanotechnology — including ethical, economic and legal implications — and must actively work to inform the public about nanotechnology. The NNI should continue to confront societal issues in an open, straightforward, and science-based manner.

Some critics of the NNI hold deep reservations about the ethical, economic, and legal implications of nanotechnology. Some of these concerns are common to many technologies, such as the allocation of risk and benefit during manufacturing. For example, a neighborhood located near a production facility may bear risks associated with exposure to the byproducts (or products) of manufacturing, while gaining few of the benefits. Concerns about possible adverse effects of nanoscale particles on human health and the environment resulting from their small particle size and unique characteristics may result in increased attention to such costs and benefits with

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[79] *Approaches to Safe Nanotechnology: An Information Exchange with NIOSH*, National Institute for Occupational Safety and Health, July 2006.

[80] *Progress Toward Safe Nanotechnology in the Workplace*, National Institute for Occupational Safety and Health, June 2007.

[81] *NIOSH Update: NIOSH Draft Offers Interim Guidance on Medical Screening of Workers Potentially Exposed to Engineered Nanoparticles*, National Institute for Occupational Safety and Health, December 13, 2007.

respect to nanoscale material production. Currently, nanotechnology EHS risks are unknown and may be acute or pose no more risk than other manufacturing processes.

Privacy rights are another issue associated with the products of nanotechnology. Nanotechnology may enable the production of highly sensitive, inexpensive sensors that could be deployed ubiquitously in commercial and public settings. While these sensors may allow check-out-free purchases from stores, or monitor the environment for toxic substances, critics argue that they could also impinge on the privacy rights of individuals if, for example, the sensors could detect chemicals related to the use of tobacco, alcohol, or illegal substances without the permission of the individual. Such information might be later applied in law enforcement, life insurance, health insurance, or employment decisions.[82] Others express concern that the economically disadvantaged and less educated — both individuals and nations — might be unable to take part in the benefits that nanotechnology products could offer.[83]

On the legal front, innovations in nanotechnology are already presenting unique challenges to the U.S. Patent and Trademark (USPTO). For example, U.S. case law generally prohibits patenting where the sole element of novelty is a change in size, the characteristic most obviously associated with nanotechnology.[84] In addition, many nanotechnology innovations involve multiple disciplines. Since the USPTO structure for examining patents is discipline-based, an examiner may not have all of the requisite expertise for the examination, affecting both their ability to conduct the examination, and the speed at which it can be done. USPTO also has acknowledged the need to accelerate the speed of nanotechnology-related patent applications. According to John Doll, Commissioner of Patents, the agency is hampered in its ability to recruit and retain patent examiners with the requisite skills to handle nanotechnology patents given the "more generous offers [patent examiners get] from the private sector."[85] Doll said that efforts have been made to improve hiring and retention at USPTO, and that a new processes has been established allowing an accelerated examination of applications.[86]

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[82] Moore, Fiona M., "Implications of Nanotechnology Applications: Using Genetics as a Lesson," *Health Law Review*, Vol. 10, No. 3, 2002. [http://www.law.ualberta.ca/centres/hli/pdfs/hlr/v10_3/10.3moorefrm.pdf]

[83] Smith, Richard H.,"Social, Ethical, and Legal Implications of Nanotechnology," *Societal Implications of Nanoscience and Nanotechnology* (The Netherlands:Kluwer Academic Publishers, 2001).

[84] *Nanotechnology Patents: Issues for Nanotechnology Inventions*, Dorsey and Whitney, LLP, May 9, 2005.

[85] Doll, John, Commissioner of Patents, U.S. Patent and Trademark Office, Letter to the Editor, *Small Times*, April 23, 2007. [http://www.smalltimes.com/Articles/Article_Display.cfm?ARTICLE_ID=290818&p=109]

[86] Ibid.

Nanotechnology Legislation in the 110th Congress

S. 1199/H.R. 2436 — Nanotechnology in the Schools Act

S. 1199, the Nanotechnology in the Schools Act, was introduced on April 24, 2007. Companion legislation, H.R. 2436, was introduced on May 22, 2007. The bill seeks to strengthen the capacity of U.S. secondary schools and institutions of higher education to prepare students for careers in nanotechnology by providing grants to those schools and institutions.

Under the legislation, the Director of the National Science Foundation is directed to establish a nanotechnology in the schools program. This program would award grants of not more than $150,000 to public or charter secondary schools offering advanced science courses and to institutions of higher education. These grants would be for the purchase of nanotechnology equipment and software and the provision of nanotechnology education to students and teachers. Institutions must provide non-federal matching funds of 25% of the grant amount, but this provision can be waived for institutions with endowments of $5 million or less.

The bill authorizes $15 million for the program in FY2008, and such sums as may be necessary for FY2009 through FY2011. S. 1199 was referred to the Senate Committee on Health, Education, Labor, and Pensions. H.R. 2436 was referred to the House Science and Technology Committee's Subcommittee on Research and Science Education.

S. 1547 — National Defense Authorization Act for Fiscal Year 2008 (Incorporating the Provisions of S. 1425)

S. 1425 was introduced on May 17, 2007. The purpose of S. 1425 was to enhance the Department of Defense's nanotechnology R&D program. The provisions of S. 1425 were later incorporated in S. 1547, the National Defense Authorization Act for Fiscal Year 2008, as section 255. The bill would amend language in the Bob Stump National Defense Authorization Act for Fiscal Year 2003 relating to the defense nanotechnology R&D program. Section 255 of S. 1547 would:

- revise the nanotechnology R&D program purposes;
- replace the Director of Defense Research and Engineering with the Under Secretary of Defense for Acquisition, Technology, and Logistics as the program administrator responsible for overseeing coordination of the nanotechnology R&D program with other departments and agencies participating in the NNI;
- outline program activities, including the establishment of research priorities; development of a strategic plan for defense nanotechnology R&D that is integrated with the strategic plan for the NNI; and establishment of a strategy for transitioning research results into products needed by DOD, including support for

development of nanomanufacturing capabilities and a nanotechnology defense industrial base; and

- extend program reporting requirements through 2013.

The bill also requires a report from the Comptroller General to the congressional defense and appropriations committees on progress made by DOD in achieving the purposes of the program. S. 1425 was referred to the Senate Committee on Armed Services. The provisions of this bill have been incorporated in section 255 of S. 1547, the Department of Defense Authorization Act for Fiscal Year 2008.

H.R. 3235 — Nanotechnology Advancement and New Opportunities Act

H.R. 3235, the Nanotechnology Advancement and New Opportunities Act, was introduced on July 31, 2007. The purpose of the bill is to ensure the development and responsible stewardship of nanotechnology. The bill would:

- establish a $100 million Nanomanufacturing Investment Partnership at the Department of Commerce to work with private investors to advance the commercialization of nanomanufacturing technologies and to increase the commercial application of federally supported research results;

- establish a tax credit of up to $10 million for the purchase of stock in qualified nanotechnology companies;

- establish a grant program within the DOC to support the establishment and development of nanotechnology incubators;

- authorize $10 million for the NSF to establish a center for the development of computer-aided design tools for nanotechnology applications;

- authorize an annual appropriation of $30 million for the DOE to conduct a grant program for nanotechnology research to address the need for clean, cheap, renewable energy;

- authorize an annual appropriation of $30 million for the EPA for a grant program for nanotechnology research to address technologies for the remediation of pollution and other environmental protection technologies;

- authorize an annual appropriation of $30 million for the DHS to conduct a grant program for nanotechnology research to address the need for sensors and materials related to homeland security needs;

- authorize an annual appropriation of $30 million for the DHHS to conduct a grant program for nanotechnology research to address health-related applications;
- require the Director of the NNCO to prepare a report to Congress on a nanotechnology research strategy for government and industry that will ensure the development and responsible stewardship of nanotechnology;
- provide a tax credit of 50% for nanotechnology education and training expenses for businesses and individuals;
- authorize an annual appropriation of $15 million for FY2008 through FY2011 for the NSF to conduct a grant program for the development of curriculum materials for interdisciplinary nanotechnology courses at institutions of higher education;
- direct the NSF to establish, through its Advanced Technological Education program, a program to encourage manufacturing companies to enter into partnerships with occupational training centers for the development of training to support nanomanufacturing; and
- direct the Secretary of Energy to submit a report to Congress containing a strategy for increasing interaction among scientists and engineers at DOE national laboratories and the informal science education community to prepare appropriate exhibits for school age children and the general public.

On July 31, 2007, H.R. 3235 was referred to the House Science and Technology Committee's Subcommittee on Research and Science Education; the House Ways and Means Committee; the House Energy and Commerce Committee's Subcommittee on Commerce, Trade and Consumer Protection; and the House Homeland Security Committee's Subcommittee on Emerging Threats, Cybersecurity, and Science and Technology.

S. 1372 — Nanotechnology Infrastructure Enhancement Act

S. 1372, the Nanotechnology Infrastructure Enhancement Act, was introduced on May 11, 2007. The purpose of the bill is to improve the national nanotechnology infrastructure by establishing a Nanoscale Science and Engineering Center or node on the National Nanotechnology Infrastructure Network located in an EPSCoR (Experimental Program to Stimulate Competitive Research) state.[87] The bill would:

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[87] According to the National Science Foundation, twenty-four states, the Commonwealth of Puerto Rico, and the U.S. Virgin Islands are currently eligible to compete in the National Science Foundation's EPSCoR program opportunities. The states are: Alabama, Alaska, Arkansas, Delaware, Hawaii, Idaho, Kansas, Kentucky, Louisiana, Maine, Mississippi, (continued...)

- require the Director of the NSF to establish a geographically diverse, interdisciplinary Center for Nanotechnology Research and Engineering focused on either the science and engineering of manufacturing at the nanoscale in multiple dimensions or nanotechnology for sustainable energy, water, agriculture, and the environment;
- allow the center to be a Nanoscale Science and Engineering Center or a National Nanotechnology Infrastructure Network node;
- require that the center shall include a lead academic institution located in an EPSCoR state and at least one additional academic institution located in a second EPSCoR state, while permitting the center to include other institutions within or outside of the United States; and
- require the center to conduct state-of-the-art research on nanomanufacturing; collaborate with other NSF grantees, and with grantees from other federal agencies, working on nanomanufacturing; share resources with the programs of other NSF grantees for the purpose of mutual advantage; and work toward a nanomanufacturing network that encourages extensive industrial collaboration.

Concluding Observations

Many expect nanotechnology to bring significant economic and societal returns. The United States was the first government to launch a national-level nanotechnology program and has invested more than any other nation. As a result of this focus and these sustained investments, many experts believe that the United States enjoys a technological leadership position in nanotechnology. Other nations are investing heavily and some industrialized and emerging economies have formidable capabilities in nanotechnology. Assessments of the National Nanotechnology Initiative have concluded that the effort is well-managed and has been successful in achieving its objectives so far. However, these assessments have recognized that the NNI faces a variety of challenges in ensuring that the full promise of nanotechnology is realized and that the United States remains the global leader in nanoscale science, engineering, and technology.

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[87] (...continued)
Montana, Nebraska, Nevada, New Hampshire, New Mexico, North Dakota, Oklahoma, Rhode Island, South Carolina, South Dakota, Tennessee, Vermont, West Virginia, and Wyoming. [http://www.nsf.gov/od/oia/programs/epscor/eligible.jsp] For more information on EPSCoR, see CRS Report RL30930, *U.S. National Science Foundation: Experimental Program to Stimulate Competitive Research (EPSCoR)*, by Christine M. Matthews.

Congress may choose to address some or many of the issues addressed in the body of this report in the course of deliberation on the reauthorization of the 21st Century Nanotechnology R&D Act of 2003 or, alternatively, in separate legislation.

The 21st Century Nanotechnology R&D Act's funding authorizations extend through FY2008. Action is being considered in both the House and Senate on reauthorization of the program. Possible topics for consideration in the reauthorization process include budget authorization levels for the covered agencies; R&D funding levels, priorities, and balance across the program component areas; administration and management of the NNI; translation of research results and early-stage technology into commercially viable applications; environmental, health, and safety issues; ethical, legal, and societal implications; education and training for the nanotechnology workforce; metrology, standards, and nomenclature; public understanding; and international dimensions. Consideration may also be given to the establishment of an independent review panel and to coordination of the timing for the NNAP assessment, the NRC assessment, and the NSET subcommittee's strategic plan for the NNI.

Appendix A. Selected Reports on the National Nanotechnology Initiative

Reports of the Nanoscale Science, Engineering, and Technology Subcommittee of the National Science and Technology Council

The National Nanotechnology Initiative Strategic Plan. December 2007.

The National Nanotechnology Initiative: Research and Development Leading to a Revolution in Technology and Industry, Supplement to the President's FY2008 Budget. July 2007.

The National Nanotechnology Initiative: Environmental, Health, and Safety Research Needs for Engineered Nanoscale Materials. September 2006.

The National Nanotechnology Initiative: Research and Development Leading to a Revolution in Technology and Industry, Supplement to the President's FY2007 Budget. July 2006.

The National Nanotechnology Initiative: Research and Development Leading to a Revolution in Technology and Industry, Supplement to the President's FY2006 Budget. March 2005.

The National Nanotechnology Initiative Strategic Plan. December 2004.

Nanotechnology in Space Exploration. August 2004.

Nanoscience Research for Energy Needs. Report from a workshop held in March 2004.

Instrumentation and Metrology for Nanotechnology. Report from a workshop held in January 2004.

Nanotechnology: Societal Implications-Maximizing Benefits for Humanity. Report from a workshop held in December 2003.

Nanobiotechnology. Report from a workshop held in October 2003.

Regional, State, and Local Initiatives in Nanotechnology. Report from a workshop held in September-October 2003.

National Nanotechnology Initiative: Research and Development Supporting the Next Industrial Revolution, Supplement to the President's FY2004 Budget. August 2003.

Nanotechnology and the Environment. Report from a workshop held in May 2003.

National Nanotechnology Initiative: The Initiative and Its Implementation Plan, Detailed Technical Report Associated with the Supplemental Report to the President's FY2003 Budget. June 2002.

National Nanotechnology Initiative: The Initiative and Its Implementation Plan, Detailed Technical Report Associated with the Supplemental Report to the President's FY2001 Budget. July 2000.

Report of the Interagency Working Group on Nanoscience, Technology, and Engineering (NSET Subcommittee Predecessor)

Nanotechnology: Shaping the World Atom by Atom. 1999.

Agency Reports

NIOSH Update: NIOSH Draft Offers Interim Guidance on Medical Screening of Workers Potentially Exposed to Engineered Nanoparticles, National Institute for Occupational Safety and Health. December 2007.

Progress Toward Safe Nanotechnology in the Workplace, National Institute for Occupational Safety and Health. June 2007.

Approaches to Safe Nanotechnology in the Workplace, National Institute for Occupational Safety and Health. July 2006.

Nanoscale Science, Engineering, and Technology in DOE's Office of Basic Energy Sciences, U.S. Department of Energy. February 2003.

External Reviews

A Matter of Size: Triennial Review of the National Nanotechnology Initiative, National Research Council. 2006.

The National Nanotechnology Initiative at Five Years: Assessment and Recommendations of the National Nanotechnology Advisory Panel, President's Council of Advisors on Science and Technology (acting as the National Nanotechnology Advisory Panel). May 2005.

Small Wonders, Endless Frontiers: A Review of the National Nanotechnology Initiative, National Research Council. June 2002.

Appendix B. List of NNI and Nanotechnology-Related Acronyms

ASTRA	Alliance for Science and Technology Research in America
CNST	Center for Nanoscale Science and Technology
CS	Committee on Science
CT	Committee on Technology
CSREES	Cooperative State Research, Education, and Extension Service
DHHS	Department of Health and Human Services
DHS	Department of Homeland Security
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOJ	Department of Justice
DOT	Department of Transportation
EHS	Environmental, health, and safety
ELSI	Ethical, legal, and societal implications
EPA	Environmental Protection Agency
EOP	Executive Office of the President
EPSCoR	Experimental Program to Stimulate Competitive Research
FHWA	Federal Highway Administration
GIN	Global Issues in Nanotechnology working group
ISO	International Standards Organization
IWGN	Interagency Working Group on Nanotechnology
NASA	National Aeronautics and Space Administration
NCI	National Cancer Institute
NEHI	National Environmental and Health Implications working group
NGO	Non-governmental organization
NIH	National Institutes of Health
NILI	National Innovation and Liaison with Industry working group
NIOSH	National Institute of Occupational Safety and Health
NIST	National Institute of Standards and Technology
NNAP	National Nanotechnology Advisory Panel
NNCO	National Nanotechnology Coordination Office
NNI	National Nanotechnology Initiative
NNIN	National Nanotechnology Infrastructure Network
NNN	National Nanomanufacturing Network
NNP	National Nanotechnology Program
NPEC	Nanotechnology Public Engagement and Communications working group
NRC	National Research Council
NSET	Nanoscale Science, Engineering, and Technology subcommittee
NSF	National Science Foundation

NSEC	Nanoscale Science and Engineering Center
NSRC	Nanoscale Science Research Centers
NSTC	National Science and Technology Council
OECD	Organization for Economic Cooperation and Development
OMB	Office of Management and Budget
OSTP	Office of Science and Technology Policy
PCA	Program Component Areas
PCAST	President's Council of Advisors on Science and Technology
R&D	Research and development
SBIR	Small Business Innovation Research
STTR	Small Business Technology Transfer Research
TSA	Transportation Security Administration
USDA	U.S. Department of Agriculture
USPTO	U.S. Patent and Trademark Office