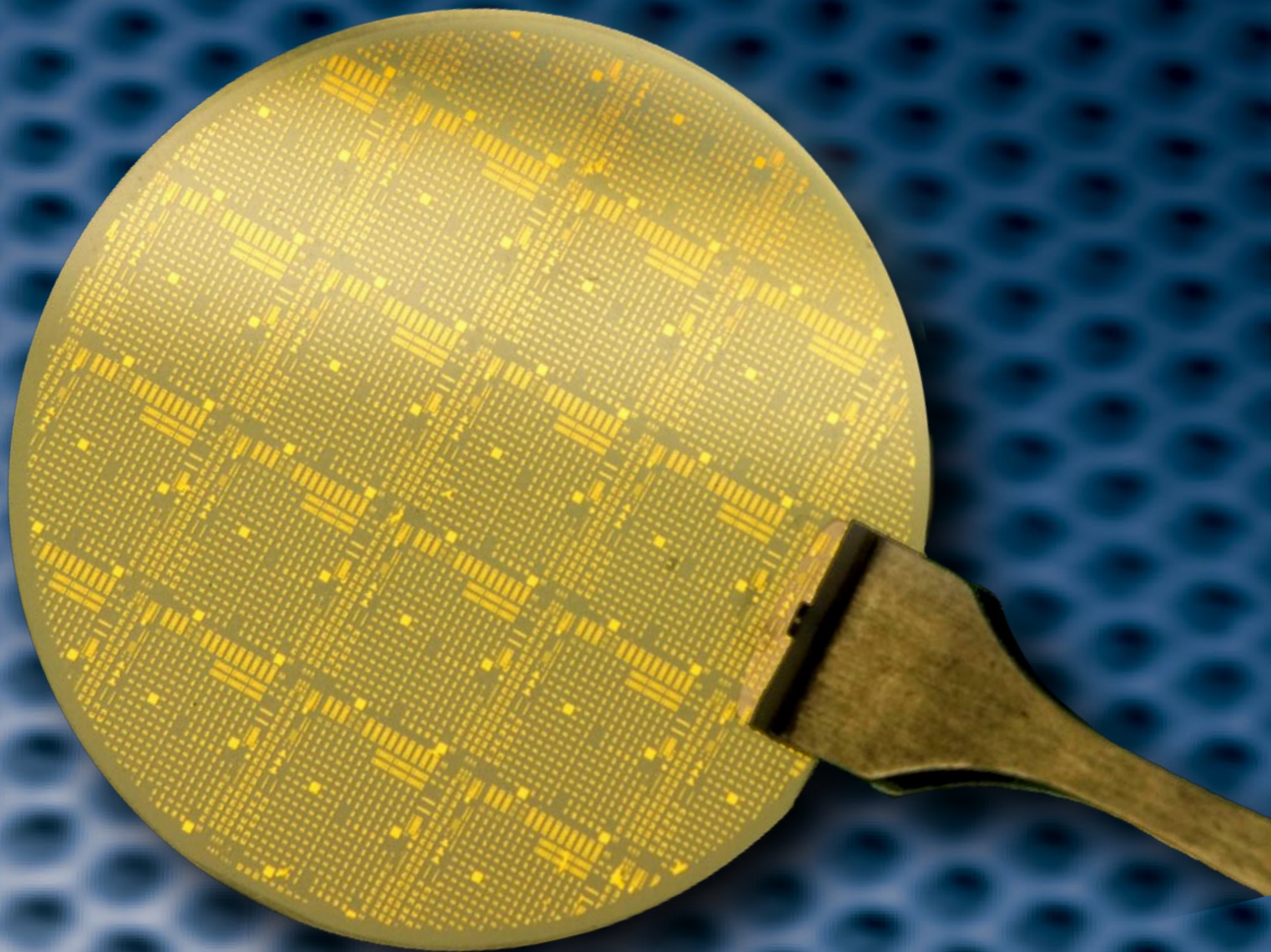


THE NATIONAL NANOTECHNOLOGY INITIATIVE

*Research and Development Leading to a
Revolution in Technology and Industry*



Supplement to the President's FY 2012 Budget

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About the National Science and Technology Council

The National Science and Technology Council (NSTC) was established by Executive Order on November 23, 1993. The Cabinet-level council is the principal means by which the President coordinates science, space, and technology policies across the Federal Government. The NSTC coordinates the diverse parts of the Federal research and development enterprise. An important objective of the NSTC is the establishment of clear national goals for Federal science and technology investments in areas ranging from nanotechnology and health research to improving transportation systems and strengthening fundamental research. The Council prepares research and development strategies that are coordinated across Federal agencies to form a comprehensive investment package aimed at accomplishing multiple national goals. To obtain additional information regarding the NSTC, visit the NSTC website at <http://www.ostp.gov/cs/nstc>.

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The Office of Science and Technology Policy (OSTP) was established by the National Science and Technology Policy, Organization, and Priorities Act of 1976. OSTP's responsibilities include advising the President in policy formulation and budget development on all questions in which science and technology (S&T) are important elements; articulating the President's S&T policies and programs; and fostering strong partnerships among Federal, state, and local governments, and the scientific communities in industry and academia. The Director of OSTP also serves as Assistant to the President for Science and Technology and manages the NSTC for the President. For additional information regarding OSTP, visit the OSTP website at <http://www.ostp.gov/>.

About this document

This document is a supplement to the President's 2012 Budget Request submitted to Congress on February 14, 2011. It gives a description of the activities underway in 2010 and 2011 and planned for 2012 by the Federal Government agencies participating in the National Nanotechnology Initiative (NNI), primarily from a programmatic and budgetary perspective. It is based on the NNI Strategic Plan released in February 2011 and reports actual investments for 2010, estimated investments for 2011 and requested investments for 2012 by program component area (PCA), as called for under the provisions of the 21st Century Nanotechnology Research and Development Act (Public Law 108-153). Additional information regarding the NNI is available on the NNI website at <http://www.nano.gov/>.

About the cover

Background image: Graphene is a state of carbon that produces a hexagonal, honeycombed-like lattice in two dimensions, but is only one atom thick in the third dimension. Generated using a cryogenic scanning tunneling microscope, this background is a topographic image of a multilayer epitaxial graphene sample grown on silicon carbide (SiC). In addition to their unique property of being only one atomic layer thick, such graphene lattices have very interesting physical properties, in this case possessing unique electronic structure and a half-integer quantum Hall effect. The background image shows a section about 5 nm by 5 nm in actual extent. This research was performed by a team from the National Institute of Standards and Technology, Georgia Tech, the University of Maryland, and the University of Texas at Austin, and was funded by the National Science Foundation, the Semiconductor Research Corporation's Nanotechnology Research Initiative, and the Keck Foundation (courtesy of Joseph Strosio, NIST).

Central image: Two-inch-diameter wafer of graphene transistors on an SiC substrate. The graphene was grown at a government laboratory (Naval Research Laboratory), the devices were fabricated at an industrial laboratory (Hughes Research Laboratory), and the collaboration was funded and administered by the Defense Advanced Research Projects Agency. This collaboration has fabricated large numbers of these transistors across full wafers (as shown in the photograph). These graphene transistors have critical dimensions as small as two micrometers and operate at frequencies above 10 gigahertz. Although other components are larger, the active regions of the transistors are one atomic layer thick (courtesy of Eric Snow, NRL).

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The National Nanotechnology Initiative

Research and Development Leading to a Revolution
in Technology and Industry



Supplement to the President's 2012 Budget

February 2011

Subcommittee on Nanoscale Science, Engineering, and Technology
Committee on Technology
National Science and Technology Council

Report prepared by

NATIONAL SCIENCE AND TECHNOLOGY COUNCIL
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SUBCOMMITTEE ON NANOSCALE SCIENCE, ENGINEERING, AND TECHNOLOGY (NSET)

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NATIONAL SCIENCE AND TECHNOLOGY COUNCIL
WASHINGTON, D.C. 20502

February 22, 2011

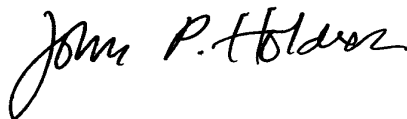
MEMBERS OF CONGRESS:

I am pleased to forward with this letter the multi-agency National Nanotechnology Initiative (NNI) Supplement to the President's Budget for Fiscal Year 2012 and annual report. This document briefly describes the programs and coordinated activities taking place across the 25 agencies participating today in the NNI – an initiative that has been a leading model of interagency coordination and collaboration for over a decade. Nanotechnology research and development (R&D) is inherently multidisciplinary and its rate of progress depends on strong interagency communication, coordination, and collaboration within the framework of the National Science and Technology Council to leverage expertise throughout the Federal Government.

The proposed NNI budget for Fiscal Year (FY) 2012 of \$2.1 billion will advance our understanding of nanoscale phenomena and our ability to engineer nanoscale devices and systems that address national priorities and global challenges consistent with the President's *Strategy for American Innovation* in such areas as renewable energy, next-generation electronics, and sustainable manufacturing. At the same time, the NNI investment sustains vital support for the fundamental, groundbreaking R&D and research infrastructure (world-class centers, networks, and user facilities) as well as education and training programs that collectively constitute a major wellspring of innovation in the United States. Finally, our nanotechnology R&D investment continues the NNI's strategic and integrated approach to addressing environmental, health, societal, and ethical issues raised by nanotechnologies.

The United States must continue to lead the way in nanotechnology and emerging technology innovation. The Nation's economic growth and global competitiveness depend on it. The NNI reflects a longstanding commitment to broad-based support of integrated, coordinated applications and implications R&D that will enable America to out-innovate, out-educate, and out-build the rest of the world. To these ends, thank you for your commitment and support.

Sincerely,

A handwritten signature in black ink, reading "John P. Holdren". The signature is fluid and cursive, with the first name "John" being the most prominent.

John P. Holdren
Assistant to the President for Science and Technology
Director, Office of Science and Technology Policy

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1. INTRODUCTION AND OVERVIEW

Overview of the National Nanotechnology Initiative

The National Nanotechnology Initiative (NNI) is a U.S. Government research and development (R&D) program of twenty-five agencies working together toward the common challenging vision of “*a future in which the ability to understand and control matter at the nanoscale leads to a revolution in technology and industry that benefits society.*”¹ The combined, coordinated efforts of these agencies have accelerated discovery, development, and deployment of nanotechnology towards both agency missions and the broader national interest. Established in 2001,² the NNI involves the nanotechnology-related activities of the 25 agencies shown in Table 1, 15 of which have specific budgets for nanotechnology R&D for 2012.

The National Nanotechnology Initiative is managed within the framework of the National Science and Technology Council (NSTC), the Cabinet-level council by which the President coordinates science and technology policy across the Federal Government. The Nanoscale Science, Engineering, and Technology (NSET) Subcommittee of the NSTC’s Committee on Technology coordinates planning, budgeting, program implementation, and review of the initiative. The NSET Subcommittee is composed of representatives from agencies participating in the NNI. A listing of official NSET Subcommittee members is provided at the front of this report. Contact information for NSET Subcommittee participants is provided in Appendix B. The National Nanotechnology Coordination Office (NNCO) acts as the primary point of contact for information on the NNI; provides technical and administrative support to the NSET Subcommittee; supports the subcommittee in the preparation of multiagency planning, budget, and assessment documents, including this report; develops, updates, and maintains the NNI website, <http://www.nano.gov>, and provides public outreach on behalf of the NNI.

The NSET Subcommittee has established four working groups to support key NNI activities that the subcommittee recognizes will benefit from focused interagency attention. These are the Global Issues in Nanotechnology (GIN) Working Group; the Nanotechnology Environmental and Health Implications (NEHI) Working Group; the Nanomanufacturing, Industry Liaison, and Innovation (NILI) Working Group; and the Nanotechnology Public Engagement and Communication (NPEC) Working Group.

What is Nanotechnology?

Nanotechnology is the understanding and control of matter at dimensions between approximately 1 and 100 nanometers, where unique phenomena enable novel applications. Encompassing nanoscale science, engineering, and technology, nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale.

A nanometer is one-billionth of a meter. A sheet of paper is about 100,000 nanometers thick; a single gold atom is about a third of a nanometer in diameter. Dimensions between approximately 1 and 100 nanometers are known as the nanoscale. Unusual physical, chemical, and biological properties can emerge in materials at the nanoscale. These properties may differ in important ways from the properties of bulk materials and single atoms or molecules.

¹ *The National Nanotechnology Initiative Strategic Plan* (NSTC, Washington DC, 2011; <http://nano.gov/nnistrategicplan211.pdf>), p. 4.

² **General note:** In conformance with Office of Management and Budget style, references to years in this report are to fiscal years unless otherwise noted.

1. Introduction and Overview

The February 2011 NNI Strategic Plan sets out the vision for the NNI stated above. The plan specifies four goals aimed at achieving that overall vision: (1) advance a world-class nanotechnology research and development program; (2) foster the transfer of new technologies into products for commercial and public benefit; (3) develop and sustain educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology; and (4) support responsible development of nanotechnology. For each of the goals, the plan identifies specific objectives toward collectively achieving the NNI vision.

The plan also lays out eight NNI investment categories (or program component areas, PCAs), each aimed at helping to achieve one or more of the above goals:

1. Fundamental nanoscale phenomena and processes
2. Nanomaterials
3. Nanoscale devices and systems
4. Instrumentation research, metrology, and standards for nanotechnology
5. Nanomanufacturing
6. Major research facilities and instrumentation acquisition
7. Environment, health, and safety
8. Education and societal dimensions

Federal agencies are investing in R&D within the above PCAs in support of national goals and agency missions. NNI funding represents the sum of the nanotechnology-related funding allocated by each of the participating agencies. Each agency separately determines its budget for nanotechnology R&D, in coordination with the Office of Management and Budget, the Office of Science and Technology Policy, and Congress. The NNI is an interagency budget crosscut in which participating agencies work closely with each other to create an integrated program. Thus, enhanced communications through the NSET Subcommittee and its working groups has led to joint coordination and collaboration in a variety of forms, including sharing of knowledge and expertise; joint sponsorship of solicitations and workshops; and leveraging of funding, staff, and equipment/facility resources at NNI participating agencies.

Purpose of this Report

This document provides supplemental information to the President's 2012 Budget and serves as the Annual Report on the NNI called for in the 21st Century Nanotechnology Research and Development Act (P.L. 108-153). In particular, the report summarizes NNI programmatic activities for 2010 and 2011, as well as those planned for in 2012. NNI budgets for 2010–2012 are presented by agency and PCA in Section 2 of this report. Information on the use of the Small Business Innovation Research (SBIR) and Small Business Technology Transfer Research (STTR) program funds to support nanotechnology research and commercialization activities, also called for in P.L. 108-153, is included at the end of Section 2. Section 3 discusses activities that have been undertaken and progress that has been made toward achieving the four goals set out in the NNI Strategic Plan and highlights external reviews of the NNI and how their recommendations are being addressed.

Table 1
List of Federal Agencies Participating in the NNI During 2011

Federal agencies with budgets dedicated to nanotechnology research and development

Consumer Product Safety Commission (CPSC)
 Department of Defense (DOD)
 Department of Energy (DOE)
 Department of Homeland Security (DHS)
 Department of Justice (DOJ)
 Department of Transportation (DOT, including the Federal Highway Administration, FHWA)
 Environmental Protection Agency (EPA)
 Food and Drug Administration (FDA, Department of Health and Human Services)
 Forest Service (FS, Department of Agriculture)
 National Aeronautics and Space Administration (NASA)
 National Institute for Occupational Safety and Health (NIOSH, Department of Health and Human Services/Centers for Disease Control and Prevention)
 National Institute of Food and Agriculture (NIFA, Department of Agriculture)
 National Institute of Standards and Technology (NIST, Department of Commerce)
 National Institutes of Health (NIH, Department of Health and Human Services)
 National Science Foundation (NSF)

Other participating agencies

Bureau of Industry and Security (BIS, Department of Commerce)
 Department of Education (DOEd)
 Department of Labor (DOL, including the Occupational Safety and Health Administration, OSHA)
 Department of State (DOS)
 Department of the Treasury (DOTreas)
 Director of National Intelligence (DNI)
 Nuclear Regulatory Commission (NRC)
 U.S. Geological Survey (USGS, Department of the Interior)
 U.S. International Trade Commission (USITC)
 U.S. Patent and Trademark Office (USPTO, Department of Commerce)

2. NNI INVESTMENTS

Budget Summary

The 2012 Budget provides \$2.1 billion for the National Nanotechnology Initiative (NNI), an increase of over \$200 million compared to the 2010 NNI level. Such an increase is consistent with the President's Strategy for American Innovation³ and reflects strong, steady growth in the NNI investment. This sustained major investment in nanotechnology research and development (R&D) across the Federal Government over the past twelve years of the NNI (spanning three Presidential Administrations and six Congresses) reflects the broad support for this program. Cumulatively totaling over \$16.5 billion since the inception of the NNI in 2001 (including the 2012 request), this support is based on nanotechnology's potential to vastly improve our fundamental understanding and control of matter, ultimately leading to a revolution in technology and industry for the benefit of society. While the NNI remains focused on fulfilling the Federal role of supporting basic research, infrastructure development, and technology transfer, the investments in 2010 and 2011 and those proposed for 2012 reflect a renewed emphasis on accelerating the transition from basic R&D advances and capabilities into innovations that support national priorities such as sustainable energy technologies, healthcare, and environmental protection. This is reflected in substantial increases in the requested nanotechnology investments for 2012 at the Department of Energy, in particular at the Advanced Research Projects Agency for Energy (ARPA-E), as well as in steadily growing investments by the National Institutes of Health and the Environmental Protection Agency. The NNI also continues to increase its investments aimed at implementing the Government's strategy for environmental, health, and safety (EHS) research.⁴ This is indicated by the proposed increase of the investments in nanotechnology R&D at the Food and Drug Administration from \$7.3 million in 2010 to \$15.0 million in the 2012 request. The Consumer Product Safety Administration also has increased its nanotechnology R&D funding from \$0.5 million in 2010 to \$2.0 million in the 2012 request. Additionally, there is increased participation in the NNI by other regulatory agencies such as the Occupational Safety and Health Administration. Increasing investments in nanotechnology R&D by many other NNI participating agencies reflect the potential for this research to support agency missions and responsibilities. Cumulative investments in EHS research since 2005 now total nearly \$575 million. Cumulative investments in education and in research on ethical, legal, and other societal implications (ELSI) of nanotechnology since 2005 total over \$390 million.

The 2012 NNI budget supports nanoscale science, engineering, and technology R&D at 15 agencies. Agencies with the largest investments are:

- DOE (research providing a basis for new and improved energy technologies)
- NIH (nanotechnology-based biomedical research at the intersection of life sciences and the physical sciences)
- NSF (fundamental research across all disciplines of science and engineering)
- DOD (science and engineering research advancing defense and dual-use capabilities)
- NIST (fundamental research and development of measurement and fabrication tools, analytical methodologies, and metrology for nanotechnology)

³ <http://www.whitehouse.gov/innovation/strategy>

⁴ *Strategy for Nanotechnology-Related Environmental, Health, and Safety Research* (February 2008): http://www.nano.gov/NNI_EHS_Research_Strategy.pdf. ((The 2010/2011 update of the 2007 NNI Strategy for Nanotechnology-Related Environmental, Health, and Safety Research is being finalized as of this printing; it will be available at <http://www.nano.gov/html/res/pubs.html> in spring 2011.)

2. NNI Investments

Other agencies investing in mission-related research are NASA, EPA, NIOSH, FDA, USDA (including both NIFA and FS), DHS, CPSC, DOT (including FHWA), and DOJ.

Table 2 shows NNI investments in 2010–2012 for Federal agencies with budgets and investments for nanotechnology R&D. Tables 3–5 list the investments by agency and by program component area (PCA).

Table 2: NNI Budget, by Agency, 2010–2012 (dollars in millions)			
Agency	2010 Actual	2011 CR*	2012 Proposed
DOE**	373.8	380.8	610.6
HHS/NIH	456.8	456.8	464.8
NSF	428.7	412.1	455.9
DOD***	439.6	415.4	368.2
DOC/NIST	114.7	95.9	115.7
NASA	19.7	20.1	32.3
EPA	17.7	17.6	19.8
HHS/NIOSH	8.5	9.5	16.5
HHS/FDA	7.3	7.3	15.0
USDA/NIFA	13.2	13.2	11.6
DHS	21.9	12.3	10.2
USDA/FS	7.1	5.0	5.0
CPSC	0.5	2.2	2.0
DOT/FHWA	3.2	2.0	2.0
DOJ	0.2	0.0	0.0
TOTAL****	1,912.8	1,850.3	2,129.6

* 2011 levels reflect the annualized amounts provided by the continuing resolution (CR) that extends through March 4, 2011.

** Funding levels for DOE include the combined budgets of the Office of Science, the Office of Energy Efficiency and Renewable Energy (EERE), the Office of Fossil Energy, and the Advanced Research Projects Agency for Energy (ARPA-E).

*** In Tables 2–3, the 2010 DOD figures include \$75 million in Congressionally directed funding that is outside the NNI plans.

**** For Tables 2–9, totals may not add, due to rounding.

Key points about the 2011 and 2012 NNI investments

- The President’s 2012 Budget includes significant funding for the three Nanotechnology Signature Initiatives that were introduced in the 2011 Budget: \$125.7 million for Nanotechnology for Solar Energy Collection and Conversion; \$84.0 million for Sustainable Nanomanufacturing; and \$98.5 million for Nanoelectronics for 2020 and Beyond, for a total of \$308.1 million. See Tables 6–8 and the accompanying text on pages 11–13 for details. Consistent with the President’s Strategy for American Innovation, the Nanotechnology Signature Initiatives aim to catalyze breakthroughs for national priorities and harness science and technology to address “grand challenges” of the 21st century.
- The most recent data on funding for nanotechnology through the SBIR and STTR programs shows a continued strong upward trend with an increase of over 30%, from \$97 million in 2008 to \$127 million in 2009. Cumulatively, the NNI agencies have funded over \$517 million of nanotechnology-related SBIR and STTR awards since 2004. Continued emphasis on SBIR and STTR funding is in keeping with the Administration’s Startup America program, which is aimed at helping entrepreneurs overcome the “valley of death” on the way to successful commercialization of science and technology breakthroughs.

2. NNI Investments

- For the first time in the NNI Budget request, funding for research on nanoscale devices and systems (PCA 3) has now overtaken fundamental nanoscale phenomena and processes (PCA 1) as the largest program component area, with \$567 million requested for 2012, compared to \$521 million for PCA 1. This reflects the evolution of basic research in some areas of nanotechnology to the successful development of nanotechnology-enabled devices and other applications, and the transition within the NNI to more use-inspired research.
- However, sustaining the basic research component of the NNI remains essential to its continued success, feeding the upstream end of the innovation pipeline. Therefore PCA 1 combined with PCA 2 (nanomaterials, \$448 million in the 2012 Budget) still account for nearly half of the total NNI funding request. The funding for PCAs 1 and 2 combined has risen from \$849 million in 2010 to \$969 million in the 2012 request.
- The 2012 Budget includes a major increase in requested investments at the Department of Energy. Totalling over \$610 million (up from \$374 million in 2010), the DOE 2012 request includes funding at ARPA-E, EERE, the Office of Fossil Energy, and the Office of Science. Much of this increase is at ARPA-E, which did not receive any money in the 2010 appropriation or in the current 2011 continuing resolution. This reflects the maturation of some aspects of nanoscale science and technology that have received long-term, sustained support from the Office of Science and other NNI basic research agencies, to the point where these areas are ripe for the development of nanotechnology-enabled applications to address the nation's energy needs.
- Following from a recommendation of the 2010 evaluation of the NNI by the President's Council of Advisors on Science and Technology (PCAST), the 2012 Budget includes a substantial increase of 44% in the NNI investment in nanomanufacturing, from \$84.8 million in 2010 to \$122.5 million in 2012. This is associated in part with the increased request for the Signature Initiative on Sustainable Nanomanufacturing, with increased investments at DOE/ARPA-E and DOE/EERE, and with a reinvigorated nanomanufacturing investment at NSF for 2012.
- The funding level for EHS research has increased by 37%, from \$90.2 million in 2010 to \$123.5 million in the 2012 request. This reflects not only increased funding at the agencies that have been supporting this research for many years, but also the addition of several agencies to the EHS budget, including research agencies NASA and USDA/FS and regulatory agencies FDA and CPSC. The NNI is also updating its strategy for EHS research, with expected completion in early calendar year 2011. For tables in this document, EHS R&D is defined as research whose primary purpose is to understand and address potential risks to health and the environment that engineered nanomaterials may pose.
- Investments in instrumentation research, metrology, and standards (PCA 4) and in major research facilities and instrumentation acquisition (PCA 6) are being sustained. While the NNI's initial infrastructure investments have been completed, there is an ongoing need to maintain and upgrade equipment and facilities, and to develop new, cutting-edge instrumentation to facilitate continued progress in nanotechnology and to encourage ready access to state-of-the-art research capabilities for accelerated commercialization efforts.
- Investments at other agencies (e.g., DHS and DOJ) fluctuate from year to year, as research portfolios are reexamined on an ongoing basis, and some nanotechnology investments are recognized sometimes only after they have been funded and their enabling nanotechnology components become evident. For example, DHS requested \$11.7 million for nanotechnology in 2010, but subsequently has reported \$21.9 million for that year, while the 2012 request has dropped to \$10.2 million.

2. NNI Investments

Table 3: Actual 2010 Agency Investments by Program Component Area
(dollars in millions)

	1. Fundamental Phenomena & Processes	2. Nanomaterials	3. Nanoscale Devices & Systems	4. Instrument Research, & Metrology, & Standards	5. Nano-manufacturing	6. Major Research Facilities & Instr. Acquisition	7. Environment, Health, and Safety	8. Education & Societal Dimensions	NNI Total
DOE	97.6	115.8	25.4	20.2	6.5	105.2	2.6	0.5	373.8
HHS/NIH	60.0	76.0	244.0	22.0	0.8	8.0	20.0	26.0	456.8
NSF	168.1	74.9	55.6	17.9	21.4	29.3	27.1	34.5	428.7
DOD	138.0	59.1	168.5	6.6	26.4	35.6	0.0	5.4	439.6
DOC/NIST	22.3	8.2	24.3	17.3	27.2	12.1	3.4	0.0	114.7
NASA	0.0	7.6	10.0	0.0	2.1	0.0	0.0	0.0	19.7
EPA	0.2	0.2	0.2	0.0	0.0	0.0	17.1	0.0	17.7
HHS/NIOSH	0.0	0.0	0.0	0.0	0.0	0.0	8.5	0.0	8.5
HHS/FDA	0.0	0.0	0.0	0.0	0.0	0.0	7.3	0.0	7.3
USDA/NIFA	1.0	2.0	5.5	0.3	0.2	0.0	3.7	0.5	13.2
DHS	1.4	11.5	5.0	4.0	0.0	0.0	0.0	0.0	21.9
USDA/FS	2.0	1.4	2.4	1.1	0.2	0.0	0.0	0.0	7.1
CPSC	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.5
DOT/FHWA	0.0	2.0	1.2	0.0	0.0	0.0	0.0	0.0	3.2
DOJ	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.2
TOTAL	490.5	358.9	542.1	89.4	84.8	190.2	90.2	66.9	1,912.8

Table 4: Estimated 2011 CR Agency Investments by Program Component Area
(dollars in millions)

	1. Fundamental Phenomena & Processes	2. Nanomaterials	3. Nanoscale Devices & Systems	4. Instrument Research, & Metrology, & Standards	5. Nano-manufacturing	6. Major Research Facilities & Instr. Acquisition	7. Environment, Health, and Safety	8. Education & Societal Dimensions	NNI Total
DOE	103.2	120.5	33.0	15.7	2.6	105.8	0.0	0.0	380.8
HHS/NIH	60.0	76.0	244.0	22.0	0.8	8.0	20.0	26.0	456.8
NSF	152.6	78.7	43.7	18.3	22.4	37.8	24.3	34.3	412.1
DOD	180.1	31.5	145.3	2.4	27.7	25.7	0.0	2.8	415.4
DOC/NIST	21.7	7.3	20.8	16.9	14.6	11.4	3.2	0.0	95.9
NASA	0.0	7.8	10.0	0.0	1.9	0.0	0.0	0.4	20.1
EPA	0.2	0.2	0.2	0.0	0.0	0.0	17.0	0.0	17.6
HHS/NIOSH	0.0	0.0	0.0	0.0	0.0	0.0	9.5	0.0	9.5
HHS/FDA	0.0	0.0	0.0	0.0	0.0	0.0	7.3	0.0	7.3
USDA/NIFA	1.2	3.0	6.0	0.3	0.2	0.0	2.0	0.5	13.2
DHS	0.8	1.5	3.0	7.0	0.0	0.0	0.0	0.0	12.3
USDA/FS	1.9	1.3	0.6	1.0	0.2	0.0	0.0	0.0	5.0
CPSC	0.0	0.0	0.0	0.0	0.0	0.0	2.2	0.0	2.2
DOT/FHWA	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	2.0
DOJ	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	521.6	328.8	507.5	83.6	70.3	188.7	85.6	64.0	1,850.3

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Table 5: Proposed 2012 Agency Investments by Program Component Area
(dollars in millions)

	1. Fundamental Phenomena & Processes	2. Nanomaterials	3. Nanoscale Devices & Systems	4. Instrument Research, & Metrology, & Standards	5. Nano-manufacturing	6. Major Research Facilities & Instr. Acquisition	7. Environment, Health, and Safety	8. Education & Societal Dimensions	NNI Total
DOE	121.3	246.3	86.8	18.4	18.3	119.5	0.0	0.0	610.6
HHS/NIH	61.0	77.0	249.0	23.0	0.8	8.0	20.0	26.0	464.8
NSF	151.6	76.3	59.2	16.6	57.2	31.5	34.5	29.0	455.9
DOD	162.8	24.1	132.6	2.1	20.3	16.4	0.0	10.0	368.2
DOC/NIST	21.1	8.9	20.0	20.0	17.5	16.6	11.6	0.0	115.7
NASA	0.0	9.3	11.7	0.0	7.3	0.0	2.0	2.0	32.3
EPA	0.0	0.0	0.0	0.0	0.0	0.0	19.8	0.0	19.8
HHS/NIOSH	0.0	0.0	0.0	0.0	0.0	0.0	16.5	0.0	16.5
HHS/FDA	0.0	0.0	0.0	0.0	0.0	0.0	15.0	0.0	15.0
USDA/NIFA	1.0	2.0	5.5	0.3	0.3	0.0	2.0	0.5	11.6
DHS	0.7	1.5	1.0	7.0	0.0	0.0	0.0	0.0	10.2
USDA/FS	1.4	1.5	0.1	1.0	0.9	0.0	0.1	0.0	5.0
CPSC	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	2.0
DOT/FHWA	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	2.0
DOJ	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	520.8	447.9	566.9	88.4	122.5	192.0	123.5	67.5	2,129.6

Nanotechnology Signature Initiatives

As first announced in the President's 2011 Budget, NNI member agencies have identified areas ripe for significant advances through close and targeted program-level interagency collaboration, with the objective of accelerating nanotechnology development in support of the President's priorities and innovation strategy. The 2011 Budget proposed funding for three Nanotechnology Signature Initiatives; significant increases in funding for all three are included in the 2012 Budget, as shown in Tables 6–8.⁵ Additional details are provided below and online at http://www.nano.gov/html/research/signature_initiatives.html.

Signature Initiative: Nanotechnology for Solar Energy Collection and Conversion

This interagency R&D initiative is aimed at using nanotechnology to help overcome current performance barriers and substantially improve the collection and conversion of solar energy. In particular the initiative aims to use nanotechnology to:

- Improve photovoltaic solar electricity generation
- Improve solar thermal energy generation and conversion
- Improve solar-to-fuel conversions

⁵ Note that these initiatives typically span multiple PCAs; information on signature initiative funding by PCA is not available.

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Table 6: Nanotechnology for Solar Energy Collection and Conversion, 2011–2012 (dollars in millions)		
Agency	2011 CR	2012 Proposed
DOE*	65.0	79.2
NSF	0.0	32.0
NIST	3.8	11.5
NASA	0.0	2.0
USDA/NIFA	0.0	1.0
TOTAL	68.8	125.7

* Funding levels for DOE include the combined budgets of the Office of Science, the Office of Energy Efficiency and Renewable Energy, and the Advanced Research Projects Agency for Energy.

Signature Initiative: Sustainable Nanomanufacturing—Creating the Industries of the Future

This interagency R&D initiative will establish manufacturing technologies for economical and sustainable integration of nanoscale building blocks into complex, large-scale systems. In particular, the focus is on:

- Design of scalable and sustainable nanomaterials, components, devices, and processes
- Nanomanufacturing measurement technologies

Table 7: Sustainable Nanomanufacturing, 2011–2012 (dollars in millions)		
Agency	2011 CR	2012 Proposed
DOE*	7.6	35.3
NSF	0.0	35.4
NIST	0.5	7.4
NASA	0.0	5.0
USDA/FS	0.2	0.9
TOTAL	8.3	84.0

* Funding levels for DOE include the combined budgets of the Office of Energy Efficiency and Renewable Energy and the Advanced Research Projects Agency for Energy.

Signature Initiative: Nanoelectronics for 2020 and Beyond

This interagency R&D initiative is aimed at discovering and using novel nanoscale fabrication processes and innovative concepts to produce revolutionary materials, devices, systems, and architectures to advance the field of electronics. The initiative has five thrust areas:

- Exploring new or alternative “state variables” for computing
- Merging nanophotonics with nanoelectronics
- Exploring carbon-based nanoelectronics
- Exploiting nanoscale processes and phenomena for quantum information science
- National nanoelectronics research and manufacturing infrastructure network (university-based infrastructure)

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Table 8: Nanoelectronics for 2020 and Beyond 2011–2012 (dollars in millions)		
Agency	2011 CR	2012 Proposed
NSF	0.0	50.0
DOE*	0.0	33.8
NIST	11.7	11.7
NASA	0.0	3.0
TOTAL	11.7	98.5

* Funding levels for DOE include the combined budgets of the Office of Science and the Advanced Research Projects Agency for Energy.

Changes in Balance of Investments by Program Component Area (PCA)⁶

P.L. 108-153 calls for this report to address changes in the balance of investments by NNI member agencies among the PCAs. These are summarized below, principally for those agencies that are reporting significant changes for 2011 and 2012.

CPSC: The Consumer Product Safety Commission expects that investments in PCA 7 (environment, health, and safety) will be maintained.

DOD: The DOD does not establish funding targets for nanotechnology, which has proven to be effectively competitive based on its contributions to meeting needs and providing opportunities for future capability. New projects are awarded on a competitive basis, and as a result, the balance of investment can change from historical levels and predictions. Nonetheless, based on the state of nanoscience and nanotechnology research and development, the DOD expects that its primary emphasis will remain in PCAs 1–3 (fundamental nanoscale phenomena and processes, nanomaterials, and nanoscale devices and systems, respectively). Historically, DOD's Technology Base (Budget Activity 1–3) investment in nanotechnology has been approximately 50% in Basic Research, about 40% in Applied Research, and about 10% in Advanced Technology Development. The bulk of the SBIR/STTR investment in nanotechnology would be categorized as functionally similar to the Applied Research category, although with a strong, directly commercializable product or process aspect more analogous to the Advanced Technology Development category. The current expectation is that these overall percentages will be continued through 2012. The DOD is increasing its focused investment in manufacturing related to nanotechnology through the Multidisciplinary University Research Initiative and STTR programs. Some examples of areas being emphasized include the following: (1) creation of highly uniform arrays of carbon nanotubes with an electronic grade junction to a silicon (Si) semiconductor substrate for ultra-lightweight, uncooled infrared detectors; (2) development of bio-enabled fabrication of electronics that bridges top-down and bottom-up approaches to achieve better than 10-nm spatial resolution; and (3) development of electrochemical techniques for patterning metals to produce nanoscale features for antennas, sensors, metamaterials, and catalysts. Renewed focus on nanomaterials in active devices and nonlithographic processing at the nanoscale is expected to lead to increasing investment in nanoscale devices and systems.

DOE: The majority of the Department of Energy components of the NNI are research programs and facilities supported by DOE's Office of Science. The investment in 2012 continues to support full operation of the five DOE Nanoscale Science Research Center (NSRC) user facilities (corresponding to

⁶ Changes are the 2012 NNI Budget compared to the actual 2010 NNI investments, as shown in this document.

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PCA 6, major research facilities and instrumentation acquisition) and an extensive array of individual university grants and DOE laboratory research programs. The Energy Frontier Research Centers (EFRCs), larger collaborative efforts in which portions of the activities relate to nanoscale science, are also continued. In 2010 DOE initiated an Energy Innovation Hub called the Joint Center for Artificial Photosynthesis (JCAP), and this support will continue in 2011 and 2012, with a portion of the activity related to nanotechnology. In addition, in 2012 DOE requests funds in the Office of Science for the initiation of a second Energy Innovation Hub focusing on batteries and energy storage, for two interagency initiatives in Nanoelectronics (i.e., the Nanotechnology Signature Initiative on Nanoelectronics for 2020 and Beyond) and in Computational Materials and Chemistry by Design, and for new research on Materials under Extremes. It is expected that portions of all of these efforts will be appropriately classified as nanoscience. From 2007 through 2010 the Office of Science supported EHS and ELSI projects reported under PCA 7 and PCA 8 that were focused on the fate and transport of nanomaterials. These projects will not continue beyond 2010 as the focus shifts to ELSI issues related to bioenergy and synthetic biology, but otherwise there have been no significant changes in the balance of Office of Science investments across the PCAs. However, the 2012 Budget includes an increase of \$183 million in requested funding at ARPA-E for projects related to nanomaterials (PCA 2), nanoscale devices and systems (PCA 3), and nanomanufacturing (PCA 5).

DOT/FHWA: The Federal Highway Administration (FHWA) investment will be maintained in PCA 2 (nanomaterials) and PCA 3 (nanoscale devices and systems).

FDA: FDA will continue to conduct activities in PCA 7 (environment, health, and safety). Together, these investments continue to support responsible development of nanotechnology.

IC/DNI: The National Reconnaissance Office (NRO) has started to invest in PCA 5, nanomanufacturing, and has entered into a Memorandum of Understanding with the Office of the Secretary of Defense Title III Defense Production Act to develop a pilot production plant to manufacture carbon nanotube sheets and threads in volume.

NASA: Nanotechnology investments by NASA are focused in four key areas: engineered materials and structures; energy generation, storage, and distribution; propulsion; and electronics, sensors, and devices. These investments are well aligned with the NNI PCAs 2, 3, and 5—nanomaterials, nanoscale devices and systems, and nanomanufacturing. Overall NASA investments in nanotechnology increased by about \$4 million from 2009 to 2010, primarily due to a growth in SBIR/STTR funding in each of these three PCAs. Although only a slight growth in nanotechnology-related funding is expected in 2011, an additional \$10 million will be invested in 2012 in support of the three Nanotechnology Signature Initiatives: \$5 million for Sustainable Nanomanufacturing, \$3 million for Nanoelectronics for 2020 and Beyond, and \$2 million for Nanotechnology for Solar Energy Collection and Conversion. This additional funding will come from the Office of the Chief Technologist Space Technology Program.

NIH: NIH does not anticipate significant changes to its balance of investments in the NNI PCAs. A large proportion of the more than 25% increase between 2009 and 2010 resulted from a small number of large multi-year-funded awards using 2010 funds and American Recovery and Reinvestment Act (ARRA) funding. While the multi-year projects continue for the next several years, the funding for such projects will be reflected in current financial reports due to the timing of the grant process. PCAs with smaller investments are subject to large changes since there is a constant and revolving turnover of projects. However, the investment strategy has not been changed.

NIOSH: NIOSH does not anticipate any significant changes in overall investment in its nanotechnology research program, which currently falls entirely within PCA 7 (environment, health, and safety). However,

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emphasis on certain components of the NIOSH program may be increased in the future based on an ongoing effort to review and adjust the NIOSH Strategic Plan. NIOSH will continue to investigate the potential human health hazards of engineered nanomaterials by exploring their biologic mechanisms. There will also be increased emphasis on measuring worker exposures and developing effective control and risk management methods, along with developing guidance on medical surveillance.

NIST: The President's 2012 Budget request for NIST will continue to support research in nanotechnology, including additional funds for developing measurements to support the manufacture and production of nanotechnology-based products. These increases will support NIST's programs in EHS aspects of nanotechnology and in user facility instrumentation, and increase the support for measurement research necessary to enable the development of advanced solar and nanomanufacturing technologies in support of the Nanotechnology Signature Initiatives. NIST's expanded nanotechnology EHS program will provide the measurement science and measurement technology (reference materials, documentary standards, reference data, instruments, and transferable methods and models) essential to enable the safe manufacture, use, and disposal of engineered nanomaterials (ENMs) and ENM-enabled products. NIST will focus on ENMs of greatest regulatory concern based on production volume, widespread use in products, and potential hazards—namely, silver, titanium dioxide, and cerium oxide nanoparticles, carbon nanotubes, and clay-based nanocomposites. NIST will coordinate with manufacturers of ENMs and ENM-based products, other NNI agencies, particularly NIOSH, OSHA, CPSC, EPA, and major nanotechnology-related EHS university centers. To ensure that the Center for Nanoscale Science and Technology (CNST) user facility maintains the capabilities needed to effectively support industrial innovation and sustain cutting-edge measurement expertise, NIST is investing resources to ensure that it can replace and update instrumentation on a continuous and timely basis. The energy-related program will continue to develop the nanoscale measurement science and tools needed to accelerate breakthroughs in third-generation photovoltaic solar cell technologies. NIST will also develop the measurement knowledge and capabilities to enable cost-effective in-line measurement techniques for closed-loop process control, thereby overcoming a major obstacle to large-scale nanomanufacturing.

NSF: Overall NNI funding at NSF in the 2012 request will increase by \$27 million as compared to the actual 2010 investment because of research priorities in several directorates.

Signature Initiatives. The 2012 budget includes an increase in NSF funding allocated to the Signature Initiative on Nanoelectronics for 2020 and Beyond to \$50 million (equally distributed among PCAs 1, 2, and 3). The NSF contributions in 2012 for the Signature Initiative on Nanotechnology for Solar Energy Collection and Conversion (equally distributed among PCAs 1, 2, and 3) will be \$32 million. The 2012 funding of \$35.4 million for the Signature Initiative on Sustainable Nanomanufacturing is contained within PCA 5 (nanomanufacturing).

Nanomanufacturing. The full 2012 request for PCA 5 is \$57.2 million, of which \$35.4 million is for the Signature Initiative on Sustainable Nanomanufacturing. New R&D programs are aimed at enabling scaled-up, reliable, cost-effective manufacturing of nanoscale materials, structures, devices, and systems. More specifically, the increased funding will support new concepts for high-rate synthesis and processing of nanostructures, nanostructured catalysts, nanobiotechnology methods, surface engineering, design and fabrication methods for devices, and assembly of devices into nanosystems and then into larger-scale structures of relevance in industry, sustainability, and medicine. Partnerships between research centers and small businesses in the areas of manufacturing and commercialization will be strengthened while maintaining about the same level of NSF investment.

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Major Research Facilities & Instrumentation Acquisition. The 2012 request includes \$31.5 million, an increase of \$2.2 million for PCA 6 compared to 2010. This includes funding for user facilities, acquisition of major instrumentation, and other activities that develop, support, or enhance the scientific infrastructure for the conduct of nanoscale science, engineering, and technology research and development. Because the infrastructure is becoming better established, a part of those funds have transitioned into other PCAs, as part of the competitive planning process in each NSF directorate. Partnerships of research centers with small businesses in the areas of nanomanufacturing (PCA 5) and commercialization will be strengthened while maintaining about the same level of NSF investment.

An external evaluation of the NSF Nanoscale Science and Engineering Centers (NSECs) will be completed in 2011. The results will be used to evaluate establishment of 2–3 new centers using a systems approach and new methods for supporting innovation in nanotechnology.

Environmental, Health, and Safety. In 2012, funds will be transferred from several PCAs to increase NSF funding for PCA 7 (environment, health, and safety) to a total of \$34.5 million. This shift reflects the prioritization of EHS within the overall NNI portfolio. The request is for research primarily directed at EHS implications and methods for reducing the respective risks of nanotechnology development. The support for EHS represents 7.6% of the total NNI funding at NSF. Support will be provided to increase research on nanobiology as it relates to predictive toxicity of nanomaterials, and on a new generation of nanotechnology products.

USDA/FS: In 2012, Forest Service nanotechnology research will continue to place a greater emphasis on renewable nanocellulose materials from the forest. Forest Service R&D nanotechnology research investments will be allocated in nanomaterials (PCA 2), characterization and standards of renewable nanocellulose materials (PCA 4), and renewable nanocellulose materials-related manufacturing research (PCA 5) while maintaining proportional R&D investment in fundamental aspects of nanotechnology in wood utilization (PCA 1). For 2012, the Forest Service plans to broaden its nanotechnology research investments to investigate environment, health, and safety implications of nanotechnology in renewable materials (PCA 7).

Utilization of SBIR and STTR Programs to Advance Nanotechnology

As called for by the 21st Century Nanotechnology Research and Development Act, this report includes information on use of the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs in support of nanotechnology development. Five NNI agencies—DOD, NSF, NIH, DOE, and NASA—have both SBIR and STTR programs. In addition to these agencies, EPA, NIOSH, NIST, and USDA have SBIR programs. Table 9 shows agency funding for SBIR and STTR awards for nanotechnology R&D from 2004 through 2009 (the latest year for which data is available).

Some NNI agencies (e.g., EPA and NIH) have nanotechnology-specific topics in their SBIR and STTR solicitations. Some agencies (e.g., NIH and NSF) have had topical or applications-oriented solicitations for which many awardees have proposed nanotechnology-based innovations. All told, this data for 2004–2009 indicates that the NNI agencies have funded over \$517 million of nanotechnology-related SBIR and STTR awards since 2004.

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Table 9: 2004–2009 Agency SBIR and STTR Awards
(dollars in millions)

	2004			2005			2006			2007			2008			2009		
	SBIR	STTR	Total	SBIR	STTR	Total	SBIR	STTR	Total	SBIR	STTR	Total	SBIR	STTR	Total	SBIR	STTR	Total
DOD	10.5	6.9	17.4	7.5	5.5	13	12.6	5.6	18.2	8.4	4.2	12.6	19.8	2.3	22.1	19.3	3.9	23.2
NSF	11.9	0.9	12.8	12.1	5.5	17.6	13.9	1.8	15.7	13.4	3.8	17.2	10.5	7.5	18.0	13.2	7.0	20.2
NIH	9.3	2.6	11.9	11.1	5.2	16.3	15.1	2.1	17.2	18.4	1.1	19.5	29.3	1.8	31.1	23.0	3.7	26.7
NIOSH	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.0	0.1	0.4	0.0	0.4	0.7	0.0	0.7
DOE	6.8	2.8	9.6	7.7	0.4	8.1	18.2	1.6	19.8	17.4	0.8	18.2	13.8	2.7	16.5	31.9	5.7	37.6
NASA	7.2	0.6	7.8	6.0	0.0	6.0	12.1	1.5	13.6	11.7	1.5	13.2	6.2	0.8	7.0	15.0	1.7	16.7
EPA	0.6	0.0	0.6	1.0	0.0	1.0	1.2	0.0	1.2	0.5	0.0	0.5	0.7	0.0	0.7	0.7	0.0	0.7
USDA	0.8	0.0	0.8	1.0	0.0	1.0	0.7	0.0	0.7	1.1	0.0	1.1	0.9	0.0	0.9	0.5	0.0	0.5
NIST	0.5	0.0	0.5	0.1	0.0	0.1	0.1	0.0	0.1	0.3	0.0	0.3	0.4	0.0	0.4	0.4	0.0	0.4
TOTAL	47.6	13.8	61.4	46.5	16.6	63.1	74.0	12.6	86.6	71.3	11.4	82.7	81.9	15.1	97.0	104.6	22.0	126.6

3. PROGRESS TOWARDS ACHIEVING NNI GOALS AND PRIORITIES

Activities Relating to the Four NNI Goals

As called for in the 21st Century Nanotechnology Research and Development Act, the 2011 NNI Strategic Plan states that the annual interagency analysis of progress under the NNI will be provided in the annual NNI Supplement to the President's Budget. As indicated in the plan, the NNI's activities for 2010 and 2011 and plans for 2012 are reported here in terms of how they promote progress toward the four NNI goals. Goal-related activities are reported in terms of two categories of activities: (1) individual agency activities and (2) engagement with other agencies and groups and activities external to the NNI, including international activities. A brief report of progress toward the NNI goals in terms of these two categories follows. *The activities described below are only selected highlights of current and planned work of the NNI member agencies and are not an all-inclusive description of ongoing NNI activities.*

Goal 1: Advance a world-class nanotechnology research and development program

The member agencies have sustained a strategic investment in nanotechnology R&D, something that is widely recognized as essential for the development and successful exploitation of any emerging technology. The expanded investment by this Administration in nanotechnology will build on the foundation established over the past ten years and set the stage for transitioning basic research discoveries into technologies and products for the benefit of our society and the nation's economy.

Towards this goal, the NNI is (1) sustaining a variety of complementary R&D investment pathways, including single-investigator research, multi-investigator and team efforts, interdisciplinary centers of excellence, and user facilities and networks; (2) mapping the leading edge of R&D by sponsoring topical and strategy-setting workshops; (3) coordinating the NNI research and development investments across multiple agencies; and (4) stimulating collaborations and interactions across agencies, disciplines, industrial sectors, and nations. Examples of efforts toward all four components of this goal are presented below.

Individual Agency Contributions to Goal 1

DHS: The Department of Homeland Security's Science and Technology Directorate maintains active research development test & evaluation (RDT&E) programs that are aligned with this goal. Nanoscale devices and nanomaterials are important research areas in the development of advanced security screening technologies. Nanotechnology plays a central role in the function of key component technologies for portable detection systems, advanced x-ray sources, imaging systems for personnel screening, and canine training aids.

DOD: The focus and content of the DOD nanotechnology efforts are broadly associated with this goal. Nanoscience and processing of materials at the nanoscale are important aspects for increasing the specific performance of materials and items upon which future defense capability can be built. Several specific examples of DOD investments related to Goal 1 follow.

- Progress has been made in research in unconventional venues of nano-assembly, focused on nanoimprint lithography, DNA-based self-assembly, and guided self-assembly at the atomic and molecular scales. The quality of the research efforts is demonstrated by significant awards, such as

3. Progress Towards Achieving NNI Goals and Priorities

those of Navy (Office of Naval Research [ONR]) grantee Prof. Nadrian Seeman (New York University), who won the 2010 Kavli Prize for nanoscience for his pioneering contribution to structural DNA nanotechnology, and ONR grantee Prof. Andre Geim (University of Manchester), who won the 2010 Nobel Prize for Physics for his groundbreaking experiments on graphene.

- The ability to partially decouple phonon and electron transport through the design of composite semiconductor systems incorporating epitaxial nanoparticles has been experimentally demonstrated in nanostructured nanowires, thin films, and bulk materials. Theoretical models support the nanoparticle size-dependent reduction of thermal conductivity with minimal impact on electrical conductivity that has led to record thermoelectric performance in these materials. Higher efficiency, solid-state energy conversion applications enabled by these advances include fuel-flexible, portable power generation, vehicle waste heat recuperation/fuel efficiency, and electronic device/systems cooling.
- The first discrete quaternary nanocrystal based on silver, lead, antimony, and tellurium ($\text{AgPb}_m\text{SbTe}_{m+2}$ [$m = 1-18$]) has been synthesized by a low-temperature solution route, demonstrating a new approach to achieve homogeneous solid-solution alloys with size- and composition-controlled semiconductor properties otherwise unobtainable in the bulk. This class of semiconductor nanocrystals has potential applications in thermoelectric energy conversion, infrared sensing, phase change memory, and photovoltaics.
- Utilizing the principles elucidated from bacterial communication, biological circuits that will form the bases for the bottom-up design and assembly of bioelectronic circuitry have been explored. In addition, the design rules for the self-assembly of protein nanostructures have been investigated. Elucidation of such first principles of biological design will enable the design and assembly of complex molecular machines that can be incorporated into materials (e.g., fabrics and coatings) to give them a range of functionalities such as selective porosity, catalysis, information processing, and the ability to alter structure and color in response to environmental conditions.
- DOD research has resulted in the detailed study of the interactions of water-soluble semiconductor quantum dots (QDs) with the electroactive neurotransmitter dopamine. These biocompatible QD-dopamine nanoassemblies represent an important component of sensors that are used to detect a wide variety of target analytes ranging from sugars to peroxides. A series of carefully designed experiments has allowed the researchers to establish that only the quinone form is capable of acting as an electron acceptor resulting in quenching of the QD emission. The rate of quinone formation and hence QD quenching is directly proportional to pH and can therefore be used to detect changes in the pH of solutions. Using this nanoscale sensor, the researchers have been able to demonstrate pH sensing in solution and even visualize changes inside cells as cell cultures underwent drug-induced alkalosis. The research was published in the August 2010 issue of *Nature Materials*, and was sponsored by the Naval Research Laboratory's Nanoscience Institute and the Defense Threat Reduction Agency (DTRA), an example of the common internal research collaboration within DOD.
- DOD is collaborating with NSF, NIST, DOE, and the Intelligence Community on the signature initiative "Nanoelectronics for 2020 and Beyond."

DOE: The Department of Energy's support for the NNI continues to come in large part from the DOE's Office of Science through support of fundamental R&D, instrumentation, and construction and operation of major research facilities. In 2010 DOE initiated the Joint Center for Artificial Photosynthesis (JCAP), an Energy Innovation Hub aimed at developing revolutionary methods to generate fuels directly from sunlight. It is estimated that approximately 20% of the activities in this hub involve nanotechnology. A similar Energy Innovation Hub focused on batteries and energy storage is requested in 2012 and it is anticipated that a significant fraction of that effort will also involve nanotechnology. By fostering unique,

3. Progress Towards Achieving NNI Goals and Priorities

cross-disciplinary collaborations, these hubs will help advance highly promising areas of energy science and engineering from the early stage of research to the point where the technology can be handed off to the private sector. In 2012, the Office of Science has requested funds to support expanded efforts in basic research related to transformational clean energy technologies, with some portion expected to be classified as nanoscience. Significant NNI support also comes from the Office of Energy Efficiency and Renewable Energy (EERE). The EERE SunShot initiative supports research and development of nanomaterials, systems, and devices through three primary programs: the Next Generation Photovoltaics (PV), Foundational PV, and PV Technology Incubator programs.

DOE: ARPA-E is a new agency within the Department of Energy with the mission of translating scientific discoveries into revolutionary energy technologies by overcoming long-term, high-risk technological barriers. The desired outcome is to create technologies that do not exist today, but that if they did would make today's technologies obsolete and have large commercial impact. The statutory goal is to ensure U.S. technological lead as well as energy and economic security for the United States by reducing energy imports, reducing energy-related emissions, and ensuring energy efficiency across the whole economy. In 2009-2010, ARPA-E has created multiple new programs that involve R&D in nanotechnology. Examples include the following:

- Next-Gen Batteries for electric vehicles that have 10 times the performance-cost ratio of today's Li-ion batteries. Many of these batteries rely on electrochemical reactions between metals and air. Nanostructured materials are key for selective transport and reactions of metals with oxygen and hydroxyl ions.
- Carbon Capture Technologies that are both low-cost (\$25-30/tCO₂) and scalable involve a variety of nanostructured membranes and adsorbents that provide selective reactions and transport for CO₂.
- Non-Photosynthetic Biofuels involve new biological routes other than Calvin-Benson cycle to fix CO₂ using microbes that can absorb a variety of reducing equivalents, such as direct current, H₂S, etc. The interplay between nanostructured materials and these microbes is key to the performance of this new route to fuel synthesis.
- Advanced Power Electronics involves the integration of wide-bandgap semiconductors such as SiC and GaN, nanostructured low-loss and high-permeability soft magnetics, and capacitors into low-cost, high-efficiency and high-reliability power conversion devices and systems.
- Advanced Cooling Technologies focus on new approaches that are cost-effective, scalable, and those that would dramatically reduce primary energy use for cooling of buildings. This relies heavily on nanostructured materials such as membranes to selectively isolate water vapor from humid air as well as thermoelectric, thermomagnetic, and other materials for direct energy conversion.
- Grid-level storage at the cost of pumped-hydro storage requires the use and integration of nanostructured materials in novel low-cost flow batteries, as well as materials with ultrahigh strength-to-weight ratio for flywheels. These programs have attracted some of the best minds in nanoscale science and engineering into energy technologies.

In 2012, ARPA-E plans to focus on a variety of new energy technologies that will rely on nanostructured materials, nanoscale manufacturing, and integration into systems. Some possible technologies include: (a) biogenic sources of natural gas and low-cost, high-density storage of natural gas for transportation; (b) non-Fischer-Tropsch based conversion of natural gas to infrastructure-compatible liquid transportation fuels; (c) low-cost and high-performance nanostructured membranes for desalination and osmotic power generation; (d) integration and packaging of low-cost, lightweight energy storage systems for electric vehicles; and (e) bioreactor systems for scaling non-photosynthetic biofuels.

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DOT/FHWA: The Federal Highway Administration will continue to investigate nanoscale approaches for inhibiting and mitigating corrosion and cracking in structural materials and for structural health monitoring via nanoscale sensors and devices. Several efforts are also aimed at improving modeling capabilities across multiple length scales to better predict material response under complex loads and environments typically encountered in transportation systems.

IC/DNI: The National Reconnaissance Office is starting an advanced fundamental research and development effort to enhance the properties of carbon nanotubes (CNTs). Specifically, the goals are to increase CNT length from 25 micrometers to 75 or 100 micrometers for composite materials with superior strength and electrical and thermal conductivity, and to decrease direct current (DC) resistivity by 25X for 48 volt DC data center operations that can lead to savings of 5 to 10% in power consumption. These enhanced mechanical and electrical properties also hold great potential for 60 Hz alternating current (AC) high tension power lines. The other challenge is to find a resin (glue) for CNT composites for superior strength and enhanced acoustic dampening.

NASA: In 2010 nanotechnology was identified by NASA's Office of the Chief Technologist as one of 14 key technology areas critical for future NASA missions and, as such, targeted for increased investment by the agency. In late 2010 an intra-agency task force completed the draft of a 20-year roadmap for nanotechnology that identified nanotechnologies with the highest potential impact on NASA missions and key capabilities enabled by these nanotechnologies. The draft roadmap recommended four "grand challenges"—high-risk, high-payoff technology thrusts—for future funding. Following a process similar to that used by NASA in Decadal Survey planning, NASA will work with the National Research Council in 2011 to review and refine the roadmap. The National Research Council will obtain comment on the roadmap content via a publicly available website and open workshops, and it will provide NASA with a report identifying technology gaps and recommending funding priorities. The roadmap will be revised based upon this input, with a final version expected to be completed in early 2012. The completed roadmap will be used to guide future funding decisions and to develop new R&D initiatives in nanotechnology. It will be updated on an annual basis to address changing needs and funding priorities within the agency, and it will be peer-reviewed every four years to assess progress and continued relevance.

NIH: In September 2010, the Alliance for Nanotechnology in Cancer of the National Cancer Institute (NCI) funded a variety of projects for the next five years. These include (1) nine multidisciplinary Centers for Cancer Nanotechnology Excellence that are the primary components for discovery and tool development of nanotechnology in clinical oncology; (2) twelve Cancer Nanotechnology Platform Partnerships, which are designed to promote and support individual, circumscribed multidisciplinary research projects that will address major barriers and fundamental questions in cancer using innovative nanotechnology solutions; (3) six Cancer Nanotechnology Training Centers to educate and train researchers from diverse fields in the use of nanotechnology-based approaches to advance understanding of cancer biology and create new methods and tools for the prevention, diagnosis, and treatment of cancer; and (4) seven K99/R00 awards to support the transition of post-doctoral scientists working on cancer nanotechnology from mentored environments to independence.

In 2004, the National Heart, Lung, and Blood Institute (NHLBI) established the Programs of Excellence in Nanotechnology (PENs) via a Request for Applications (RFA) with the goal of creating teams to develop and apply nanotechnology solutions to the diagnosis and treatment of heart, lung, blood, and sleep disorders. NHLBI funded four multidisciplinary PENs in spring 2005, committing \$54 million over 5 years. The program was renewed in August 2010 (NHLBI-HV-10-08) with similar goals and a greater focus on clinical translation. Four contracts, totaling \$65 million, were funded for five years.

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The Nanomedicine Common Fund Initiative extended several awards in 2010 that were originally made in 2005 and 2006. The continuing awards aim to transition novel, fundamental discoveries—made during the initial funding period regarding ways to precisely control and manipulate subcellular macromolecular assemblies—toward preclinical models relevant to specific medical conditions.

In 2010, the National Institute of Biomedical Imaging and Bioengineering (NIBIB), in collaboration with National Institute of Environmental Health Sciences (NIEHS) and NCI, awarded a contract to develop and launch a nanomaterial registry whose primary function is to provide curated information on the biological and environmental interactions of well-characterized nanomaterials as well as links to associated publications, modeling tools, computational results, and manufacturing guidances. The nanomaterial registry will enable researchers to navigate among different databases and compare all types of available data.

NIST: NIST's research and development program in nanotechnology is conducted primarily within its four laboratories and two user facilities. The NIST nanotechnology program is addressing national measurement needs in energy, the environment, healthcare, information technology security, manufacturing, and physical infrastructure, as illustrated by the following examples.

- NIST researchers are making significant advances in nanoelectronics by developing energy-efficient nanowire-based devices; improving fabrication processes for Si-based molecular electronic devices; creating methods to fabricate and test spin-based devices; elucidating key properties of graphene and graphene-based devices; and developing innovative ways to measure and manipulate photons in nanophotonic applications.
- NIST is developing atom probe measurement science to further the quantitative understanding of this technique and enable its broader application in technologies ranging from semiconductor and data storage to biotechnology and optoelectronics. New methods and instrumentation are under development to accurately measure nanoscale forces traceable to SI base units,⁷ including the exploration of atomic and single-molecule forces as potential intrinsic standards. NIST researchers are also developing novel techniques for nanoparticle metrology, such as a technology for on-chip size separation and measurement of nanoparticles by three-dimensional nanofluidic size exclusion, and a data analysis method for determining the diffusion coefficient of a single nanoparticle using a series of images captured by an optical microscope.
- In 2011 NIST's Technology Innovation Program (TIP) has funded an additional \$8.67 million for nanotechnology research and development grant awards initially funded in 2010, primarily to small- and medium-sized companies. New nanotechnology research and development grant awards announced in 2011 will support volume production of nanocomposite alloy anode materials for lithium-ion batteries and synthesis of high-efficiency organic photovoltaics for scalable, cost-effective manufacturing. TIP continues to solicit industry and stakeholder white papers on other areas of critical national need that may be addressed through nanotechnology and nanotechnology-enabled R&D.

NSF: NSF supports nanoscale science and engineering in all disciplines throughout all its research and education directorates as a means to advance discovery and innovation and integrate various fields of research. The NNI enables increased interdisciplinarity in research at atomic and molecular levels for about 5,000 active awards representing more than 10 percent of the NSF portfolio. Research areas include discovery and understanding of novel phenomena, quantum control, self-assembly, and basic engineering

⁷ See the base units webpage of the International System of Units (SI) official website, http://www.bipm.org/en/si/base_units/.

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processes at the nanoscale, as well as understanding complex and emerging behavior of nanosystems, and creating nanomaterials and nanosystems by design.

In 2010 NSF sponsored an international study on long-term nanotechnology research entitled, “Nanotechnology Research Directions for Societal Needs in 2020.”⁸ The final report from this study provides an assessment of nanotechnology development in the last ten years (2000–2010) and a long-term vision of the field in the next decade (2010–2020). This study evaluated the outcomes of national investments in nanotechnology R&D, as recommended in the 1999 report, “Nanotechnology Research Directions: A Vision for the Next Decade,”⁹ which was adopted as an official document of the NSTC.

USDA/FS: In 2010, the Forest Service made a one-time additional investment in nanotechnology R&D in the amount of \$1.7 million to bring its total 2010 investment in nanotechnology R&D to \$7.1 million. The \$1.7 million is invested in systems and devices that will improve the production of cellulose nanocrystals for research purposes to break through the bottleneck in nanocellulose research by providing researchers with sufficient quantities of cellulose nanocrystals research material. Specifically, this funding will fund purchase and installation of laboratory-scale equipment to produce two 60 pound batches per week of cellulose nanocrystals and nanofibrillar cellulose from wood. The equipment is expected to be operational in the third quarter of 2011 and will provide working quantities of nanocellulose materials to support public-private research and development activities within and external to FS R&D. With sufficient quantities of research materials available, the Forest Service will continue to build a world-class nanotechnology program that will significantly impact renewable nanocellulose materials research and downstream user industries, such as the forest products industry, chemical industry, coatings industry, defense industry, electronics industry, and biomedical industry, in 2012 and beyond.

USDA/NIFA: NIFA will continue supporting NNI Goals 1 and 2 through the Nanotechnology for Agricultural and Food Systems program in the Agricultural and Food Research Initiative (AFRI) competitive grants program and others. NIFA invests in nanoscale science, engineering, and technology research that addresses a broad range of critical challenges and opportunities facing agriculture and food systems. NIFA also supports innovative ideas to develop nanotechnology-enabled solutions for global food security through improving productivity and quality, adaptation and mitigation of agricultural production systems to climate changes, improving nutritional quality of foods, and development of biology-based products and energy solutions. The program scope includes, but is not limited to, novel uses and high-value-added products of nano-biomaterials of agricultural origins for food and non-food applications, nanoscale-based sensing mechanisms and devices for reliable early detection of diseases and monitoring of physiological biomarkers for optimal agricultural production, precision agriculture technologies including ones to efficiently manage applications of agricultural chemicals and water resources, and water quality improvements. In addition, NIFA investments will support discovery and characterization of nanoscale phenomena and processes important to agricultural production species. Research on nanostructures and nanomaterials of great promise in agricultural production and processing is also applicable, as is research on applications using nanotechnology for detection and intervention to improve food safety. In addition, the NIFA SBIR program will continue broadly supporting innovation using nanotechnology in agriculture and food applications.

⁸ To be published by Springer in 2011; the 2010 NSF/WTEC preprint is available at <http://www.nsf.gov/nano> and <http://www.wtec.org/nano2/>.

⁹ Springer, 2000; the 1999 WTEC preprint is available at <http://www.wtec.org/loyola/nano/IWGN.Research.Directions/>.

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USPTO: The USPTO contributes a variety of nanotechnology-related patent data, which is used as a benchmark to analyze nanotechnology development and for trend analysis of nanotechnology patenting activity in the United States and globally.

Coordinated Activities with Other Agencies and Other Institutions Contributing to Goal 1

Multiple NNI agencies, industry: The three Nanotechnology Signature Initiatives (as outlined on pages 11–13 in Section 2 of this report) are being planned and conducted in cooperation with industry.

NIST, other agencies, industry, universities: NIST co-sponsors workshops with a wide range of partners to identify measurement needs for nanotechnology. In 2010, the following workshops were held with a variety of co-sponsors: Wires, Whiskers, and Walls: Energy Applications at the Nanoscale; Measurement & Control of Chirality (the 4th Carbon Nanotube Workshop at NIST); Washington Metro Region Nanotech Partnership Forum; Grand Challenges for Advanced PV Technologies & Measurements; Nanoscale Optics, Plasmonics, and Advanced Materials; and Measurement and Characterization in Support of Toxicology R&D (the 4th Tri-National Workshop on Standards for Nanotechnology, involving Canada, Mexico, and the United States).

NSF, NIST, nanoelectronics industry: NSF and NIST have joint partnerships with the Semiconductor Industry Association (SIA) and the Semiconductor Research Corporation (SRC) in support of the Nanoelectronics Research Initiative (NRI).

USDA/FS and industry: Recognizing the importance of nanotechnology and wood-derived cellulosic nanomaterials, the forest products industry and the USDA Forest Service have taken steps to establish a common vision and agenda focused on developing the precompetitive science and technology critical to the commercialization and economic use of cellulosic nanomaterials for new generations of products. Through public–private partnering involving industry, the Federal Government, and universities, the U.S. Forest Products Industry seeks to be the 21st century global market leader in development of science, technology, and new high-performance nanocellulose-enabled products. The U.S. forest products industry is being led in this effort by the American Forest & Paper Association’s Agenda 2020 Technology Alliance. Establishing an industry–government–university partnership provides a way to combine interests and expertise to create the science and technology needed to successfully commercialize new products and create new jobs within the United States. Related interests and expertise include the marketing and focused reduction to practice skills that are inherent in industry; the public-interest-based, national problem-solving capacities of government; and the world-class research capabilities of universities. For example, use of wood-derived nano-dimensional cellulose in nanocomposites will allow the production of much lighter-weight, hyper-strength, multifunctional materials with widespread application in many industrial manufacturing sectors. Successful partnering will help to reinvent the U.S. forest products industry; make sustainable and efficient use of America’s abundant forest resources; improve forest health and condition; and revitalize rural economies.

Goal 2: Foster the transfer of new technologies into products for commercial and public benefit

The NNI member agencies have a number of activities uniquely targeting technology transfer and commercialization, e.g., workshops to gain input from industry and the academic community, SBIR and STTR programs to fund innovations in small businesses, and forefront research infrastructure for use by all nanotechnology researchers, including those from industry. Some positive results from this effort are now evident.

Individual Agency Contributions to Goal 2

DHS: The transition of enhanced security technology to enhance the capability of DHS operational agencies is of central importance to DHS. The development and application of nanoscale materials and devices continue to provide capability improvements to component technologies for homeland security applications. One example is the development of carbon nanotube x-ray sources. In collaboration with industry partners, DHS's Science and Technology Directorate is actively pursuing the development and testing of advanced security systems that utilize component technologies with improved performance characteristics that result from the incorporation of nanoscale technology including carbon nanotube x-ray sources, as well as advanced micro- and nanoscale sensor arrays and advanced vapor preconcentrator systems for trace detection of explosives.

DOD: As basic understanding and knowledge associated with the nanoscale and engineered nanomaterials have increased, there have been more opportunities to exploit properties or processes that provide useful performance or capabilities. Current maturation efforts include research in consolidating nanocrystalline aluminum alloy 5083, conventional aluminum 5083, and boron-carbide ceramic powder to form an alloy called "trimodal aluminum." The development of this alloy will produce a material that has the strength of steel at the weight of aluminum, a 66% weight savings. Other research is addressing the utilization of nanotechnologies, with an emphasis on nanostructures, to develop miniature autonomous mobile sensors capable of detecting trace-level molecules from hidden explosive devices.

DOD research has been successful in fostering the development and insertion of specific products. Some examples are (1) coatings for high-power microwave (HPM) devices based on a new cathode with 100-nm cesium iodide coating that reduces HPM system size, weight, and power consumption; (2) nanocomposite space system insulation utilizing nanostructured silicate molecules developed and commercialized for rocket motor insulation, which reduced rocket motor insulation weight, increased erosion resistance, and reduced material costs from \$1,000/lb. to \$20/lb.; (3) a dual-band quantum well infrared camera based on a unique quantum well architecture, permitting the infrared detector to operate in the long-wave/medium-wave infrared regimes, which provides a basis for development of cameras with improved sensitivity; (4) the "Fido" TNT sensor containing novel amplifying fluorescent polymers that sense ultratrace concentrations of nitroaromatics, leading to production of the first man-made sensor that has the sensitivity to detect buried landmines by their chemical signature and that can be incorporated in a man-portable detector; and (5) nanostructured alumina/titania coatings that provide improved wear-resistance for bearings and valves, increasing coating lifetimes from hours to years, based on predictive analysis.

DOD has successfully used biological templates to direct the synthesis and assembly of bimetallic nanoparticles. The performance of these nanoparticles was demonstrated as a conductive lubricant in microelectromechanical-based electrical switches at high current with no failure through one million hot-switching cycles. The size, shape, and composition of engineered nanoparticles must be carefully controlled during manufacture to give the needed optical, electronic, catalytic, and mechanical properties. It has recently been shown that biological molecules, such as peptide chains containing up to 20 selected amino acid molecules, can be used to synthesize engineered nanoparticles. This biosynthesis approach provides a simple, flexible, real-time manufacturing capability that can produce a wide array of engineered nanoparticles in the field in response to locally identified needs. Potential applications include dechlorination of drinking water, decontamination of nerve agents, and electrically conductive lubricants.

A nanoparticle composite of zinc and carbon has been developed that self-heats via electrochemical oxidation when exposed to air. The heater was developed to heat the standard operational ration meal ready-to-eat (MRE) used by troops in the field.

3. Progress Towards Achieving NNI Goals and Priorities

Numerous electron spin-based devices have been demonstrated, including the first spin-polarized light-emitting diode (LED) and the first spin-polarized quantum dot vertical cavity surface-emitting laser. In a significant advance toward technically viable spin-based electronic devices, the capability has been demonstrated to efficiently inject a current of spin-polarized electrons from an iron thin-film contact through an aluminum oxide (Al_2O_3) tunnel barrier into silicon (Si), producing large electron spin polarization. This is a key enabling step for developing Si-based electronic devices, which are expected to provide higher performance with lower power consumption and heat generation.

Ultraporous carbon nanofoam papers have been developed. The papers' interior structures can be covered with ultrathin (<50 nm) coatings of a metal oxide (MnO_2 or FeO_x), using low-cost, scalable electroless deposition methods. The nanoscale metal oxide coating serves as a charge-storage bank, facilitated by ion-electron reactions involving cations from the electrolyte and electrons from the supporting carbon nanofoam structure. This is an essential step toward achieving high-charge discharge rates in high-energy-density batteries.

DOD-funded research has provided a process to deposit approximately 3-nm thick, electronically conductive layers of ruthenium oxide (RuO_2) onto curved silicon dioxide (SiO_2) fiber surfaces to achieve the vaunted electrical and electrochemical properties associated with ruthenium at lower cost. Because the volume fraction of ruthenium (expensive) is limited to <0.1%, this capability will provide significant cost savings.

DOE/ARPA-E: As indicated under Goal 1, ARPA-E is involved in creating and developing multiple R&D efforts that involve nanoscale science and engineering. The statutory goal of ARPA-E is to create revolutionary energy technologies that could have large commercial impact. Hence, translating developments in science and engineering into commercially viable energy technologies is key to ARPA-E's success. ARPA-E has created a dedicated commercialization team to help enable the transfer of new energy technologies into commercially viable businesses. Most ARPA-E projects contain commercialization milestones that the teams must reach. About 33% of ARPA-E funding goes to universities, 37% to small businesses, 20% to R&D labs in large businesses, 5% to national laboratories, and the rest to non-profits. In its 1.5-year existence, ARPA-E initially has invested \$151 million in its first round of funding in such new technologies. It is important to note that within one year, the private sector investment into these technologies has already exceeded \$151 million, which suggests rapid leveraging of Federal funding for commercial benefit. This spans the gamut of energy technologies: fuel synthesis, advanced batteries for transportation and grid-level storage, grid infrastructure, energy efficiency in buildings and industry, and stationary power generation. In March 2010, ARPA-E launched the first Energy Innovation Summit, which showcased not only ARPA-E funded technologies but also those that ARPA-E could not fund. This led to significant commercialization opportunities for various technologies. Based on this success, ARPA-E plans to continue the annual Summit to promote in its commercialization effort.

DOE/EERE: The Department of Energy supports nanotechnology transfer, industrial manufacturing activities, and commercialization through the Office of Energy Efficiency and Renewable Energy and its Industrial Technologies Program (ITP). In 2012, ITP's nanomanufacturing efforts will continue to translate the U.S. investment in nanotechnology to the industrial sector through nanomaterials production scale-up. Nanomaterial fabrication within the ITP portfolio will focus on applications for renewable power generation and energy storage, pollution prevention, and coatings to improve component wear resistance. Of note are advances in superhydrophobic coatings—which hold the promise of reducing the energy needed to pump liquids through pipes and reduce ice accumulation on power lines—and work on nanoscale coatings to reduce turbine blade erosion and maintain engine efficiency.

3. Progress Towards Achieving NNI Goals and Priorities

The DOE/EERE Solar Energy Technology Program (SETP) is likewise committed to fostering the transfer of nanotechnologies from the lab bench to innovative commercial products. The new PV Manufacturing Initiative was launched in 2011, and is devoted to supporting collaborative manufacturing focused R&D. The successful PV Technology Incubator program funds projects developing prototype PV components and systems and overcoming barriers to commercialization. A hallmark of the program is establishing close collaborations between awardees and scientists at national labs. Since 2007, DOE has awarded \$50 million to support the program, which has leveraged an estimated \$1.2 billion in private investments, delivering a 24-to-1 private-to-public investment ratio for U.S. taxpayers. Meanwhile, ongoing SETP program activities in the areas of systems integration and market transformation work to eliminate both technical and non-technical barriers to product commercialization.

NASA: In 2012, NASA will increase its investment in nanomanufacturing-related R&D by \$5 million, for a total of \$7.3 million, more than triple its 2010 investment. This is in direct support of Objective 2.1 in the 2011 NNI Strategic Plan and the recommendation of the 2010 PCAST evaluation of the NNI to double the NNI investment in nanomanufacturing.

NIST: NIST has invented a new nanoscale measurement method, through-focus scanning optical microscopy, which enables a conventional optical microscope to be used for three-dimensional metrology with nanoscale lateral and vertical resolution. This cost-efficient measurement method was a winner of a 2010 R&D 100 Award by *Re&D* Magazine. NIST is also developing and disseminating the next generation of electrical resistance standards that exploit the unique quantum properties of graphene at the nanoscale.

NRC: The U.S. Nuclear Regulatory Commission (NRC) is focused in part on confirmatory research to verify the safe application of new technologies in the civilian nuclear industry. Currently the agency's focus for nanotechnology is to monitor developments that might be applied within the nuclear industry in order that the NRC can carry out its oversight role.

NSF: The agency is strengthening its contributions to translational innovation programs, including AIR (Accelerating Innovation Research), GOALI (Grant Opportunities for Advancing Liaison with Industry), PFI (Partnerships for Innovation), and IUCRC (Industry University Cooperative Research Centers). NSF is also supporting partnerships with industry in centers—including NSECs, Materials Research Science and Engineering Centers (MRSECs), the National Nanotechnology Infrastructure Network (NNIN), and the Network for Computational Nanotechnology (NCN)—as well as partnerships with U.S. small businesses and large companies for projects on fundamental research with long-term goals of interest to industry. There is an increased focus on energy conversion and storage, cyber-physical systems, and synthetic biology research and education.

USPTO: The transfer of new nanotechnology-related technologies into products for commercial and public benefit depends on effective mechanisms that protect new ideas and investments in innovation and creativity. The United States Patent and Trademark Office is at the cutting edge of the nation's technological progress as the Federal agency responsible for granting patents, registering trademarks, and providing intellectual property policy advice and guidance to the Executive Branch. The USPTO has put in place several initiatives to keep pace with the rapid advances being made in nanotechnology.

The USPTO hosts a nanotechnology customer partnership forum that provides a mechanism for USPTO officials and patent stakeholders to share concerns and information related to the patenting of nanotechnology. The agency provides in-depth nanotechnology-specific training events for patent examiners to enhance the technical knowledge base of USPTO examiners. As a result of this ongoing training initiative and targeted hiring of patent examiners with specific nanotechnology experience, the

3. Progress Towards Achieving NNI Goals and Priorities

USPTO has a subset of patent examiners across all technology disciplines who serve as points-of-contact to assist other examiners with nanotechnology issues related to patent examining.

Coordinated Activities with Other Agencies and Other Institutions Contributing to Goal 2

NNI member agencies and international standards bodies: Technical experts from multiple agencies, including DOD, DOE, EPA, FDA, NCI, NIOSH, NIST, and USDA/FS, are working to develop international documentary standards in nanotechnology through the International Organization for Standardization (ISO), as coordinated by the American National Standards Institute's U.S. Technical Advisory Group to ISO TC229 (Nanotechnologies). The Federal agencies' Interagency Committee on Standards Policy, chaired by NIST, provides an additional forum for information exchange and coordination on standards policy issues relating to nanotechnology. NNI agencies are also participating in standards development activities within ASTM International's Committee E56 (Nanotechnology), the International Electrotechnical Commission Technical Committee 113 (Nanotechnology Standardization for Electrical and Electronics Products and Systems), and the Institute of Electrical and Electronics Engineers' Nanotechnology Council in developing nanotechnology-related documentary standards. This close cooperation with the American National Standards Institute helps NNI member agencies provide input reflecting U.S. priorities in the international standards arena.

NNI member agencies, Organisation for Economic Co-operation and Development (OECD): The Department of State chaired the OECD Working Party on Nanotechnology (WPN) to advise on emerging policy issues in science, technology, and innovation related to the responsible development and use of nanotechnology. The WPN is assessing business environments, international research collaboration and coordination, available indicators and statistics, and approaches to public engagement. NNI agencies are also playing a leading role in OECD's Working Party on Manufactured Nanomaterials (WPMN).

DOD, DOE, EPA, IC, NASA, NIH, NIST, NIOSH/OSHA, NSF, and USDA/FS: These agencies are collaborating in the signature initiative Sustainable Nanomanufacturing—Creating the Industries of the Future.

IC/DNI, other NNI agencies, industry: The NRO is currently enabling engineering samples of carbon nanotube radio frequency (RF) coaxial cables for commercial aircraft, and for several spacecraft to reduce launch cost, because CNT materials make lighter, higher-performance RF cable assemblies. Once certified, all copper cables can be replaced with CNT coaxial cables.

IC/DNI and other NNI agencies: The NRO has established a memorandum of agreement (MOA) with the Office of the Secretary of Defense, Director, Defense Research and Engineering's Defense Production Act Title III to expand volume nanomanufacturing of carbon nanotube sheets and threads that are essential for national defense.

IC/DNI, NASA, Air Force, industry: NASA Glen Research Center is assisting NRO by growing indium arsenide (InAs) quantum dots for 35% efficiency space solar cells with EMCOR and Rochester Institute of Technology, which has a NASA Space Act agreement. The Air Force Research Laboratory is also co-funding this project.

IC/DNI and Air Force: Air Force Space Command's Space and Missile Center is co-funding research on an initial nanomanufacturing of nanoelectronics for space with the NRO. This includes research for carbon nanotube nonvolatile memory and a 70 gigaflop digital signal processor for space.

NIST and NSF: A 2011 workshop at NIST, "The New Steel? Enabling the Carbon Nanomaterials Revolution: Markets, Metrology, Safety, and Scale-up," will support NNI efforts to identify technical

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challenges to the commercial development of high-performance, carbon-based nanomaterials, and to facilitate the formation of a public-private partnership to address those challenges.

NIST and industry: Under a cooperative research and development agreement, NIST and FEI Company are developing a more versatile ion source for use in focused ion beams. Based on the NIST magneto-optical trap ion source (MOTIS), the new technology will enable new sources of ions to be routinely used in focused ion beams for high-resolution imaging and fabrication. NIST is also working with the refrigeration and air-conditioning industries to develop nanoengineered lubricants as a cost-effective technology to improve the efficiency of chillers that cool large buildings (which consume 3% of all U.S. energy).

NSF, other NNI agencies, industry: NSF and other agencies are co-sponsoring workshops on research directions, including roadmapping workshops in support of signature initiatives, in cooperation with industrial partners. Collaborative NNI interagency efforts to develop interactions with industry sectors include working with the electronics industry, the wood and paper industry, and the food and agriculture industries.

NSF, other NNI agencies, regional, state, and local nanotechnology initiatives: NSF worked cooperatively in 2010–2011 to finalize and publish a report from the NNI workshop, “Regional, State and Local Initiatives in Nanotechnology.”¹⁰

USDA/NIFA, Canada AFMNet, NSF, NIH, EPA, NIST, USDA/FS: USDA/NIFA and the Canada Advanced Food and Materials Network held their second annual joint grantees’ conference in Washington, DC, December 10–11, 2010. Multiple agencies of the NNI, as listed, supported the conference by providing keynote speeches to highlight the research, education, and outreach achievements; vision and directions; and potential collaborative opportunities.

USPTO, other NNI agencies, international patent offices: The USPTO developed, and now maintains, the first fully expanded patent-related nanotechnology classification schedule (Class 977) of any major intellectual property office in the world. The USPTO continues working with the European and Japan Patent Offices to develop a common International Patent Classification (IPC) scheme for nanotechnology based upon the USPTO schedule. This effort includes the consideration of a harmonized definition of nanotechnology as it relates to patent examination.

Goal 3: Develop and sustain educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology

Significant progress is being made on all three aspects of Goal 3 (development and sustaining of educational resources, skilled workforce, and supporting infrastructure and tools). With respect to education and workforce development, education is among the chief objectives of NNI-funded university research. In addition, specific programs targeted at K–16 education, educating the public about nanotechnology, and improving nanotechnology curricula in U.S. schools and universities have been initiated and are growing in scale and reach. Details are provided in the following text. The extensive network of research centers, user facilities, and other infrastructure for nanotechnology research, which was a key element of the original NNI strategy, is now largely complete.¹¹

¹⁰ See <http://www.nano.gov/html/res/pubs.html>.

¹¹ See a detailed discussion of the U.S. NNI infrastructure in the NNI Supplement to the President’s FY 2008 Budget, http://www.nano.gov/NNI_08Budget.pdf, including a map that shows the location of all the centers, networks, and user facilities (p. 21) and a list of participating academic institutions and national laboratories (pp. 29–33). For an updated list, see also: <http://www.nano.gov/html/centers/nnicenters.html>.

Individual Agency Contributions to Goal 3

DHS: The DHS, Science and Technology Directorate maintains active RDT&E programs through the DHS Centers of Excellence that support this goal by providing direct program interactions with the academic community. Current activities in the development of novel detection technologies, forensic analytical methods, and canine training aids all benefit from advances in nanomaterials.

DOD: The DOD Basic Research Sciences Programs have an important mission to produce not only research products but also the future research and engineering workforce that will continue to extend our knowledge frontiers and apply that knowledge toward improving defense capabilities and meeting societal needs. This is accompanied by specific research in projects that improve our ability to do research itself through advanced instrumentation and novel techniques. Some examples of such research follow.

- DOD tools research has provided an instrument that combines the imaging capability of scanning probe microscopy with the nanomechanical measurement capabilities of instrumented indentation to create a capability to image variation of mechanical properties and topography within a test specimen. This tool will enable researchers to probe the mechanisms that determine response of nanocomposites to stress at the appropriate length scales, ultimately guiding the design of more efficient structural composites for realistic naval applications.
- DOD manufacturing tools efforts are developing a direct-write, multibeam, electron beam lithography tool with sub-10-nm spot size control that will address the DOD's need for affordable, high-performance, low-volume integrated circuits (ICs) and the commercial market's need for highly customized, application-specific integrated circuits (ASICs) in maskless direct-write nanolithography for defense applications. These tools will provide a cost-effective technology for low-volume nanoelectromechanical systems and nanophotonics initiatives within the DOD.
- A major obstacle to the realization of nanotube capabilities has been the lack of approaches for the mass production of high-quality and high-uniformity carbon nanotubes and for organizing them into useful architectures for further evaluation. DOD research has been focused on developing a template-assisted chemical vapor deposition method to produce a highly ordered array of high-quality carbon nanotubes of controlled diameter, length, and spacing on an Si substrate. This new material system gives a broadly enabling platform for future multispectral infrared and biochemical sensing applications as well as a template for researchers. This capability is important for miniaturization and for providing new sensing capabilities.

IC/DNI: The NRO plans on competitively selecting more post-doctoral researchers to work on nanotechnology challenges. It currently has two (2010-2012) and will add two more in both 2011 and 2012 for a total of six.

NASA: The Office of the Chief Technologist (OCT) began a new initiative in 2011 with the goal of creating a pipeline of highly skilled scientists and engineers needed for NASA's and the nation's technological future. The Space Technology Research Fellowship Program provides up to two years of funding for Master's degree students and four years of funding for PhD candidates in science, engineering, technology, and mathematics and gives them the opportunity to work with scientists and engineers at NASA research centers to conduct research in support of the fourteen technology areas identified by OCT (see Goal 1 discussion). While the exact number of nanotechnology-related fellowships to be funded in 2011 and 2012 has not been determined, it is anticipated that the new fellowships will be a significant component of this program.

3. Progress Towards Achieving NNI Goals and Priorities

NIH: With the renewal of the NCI's Alliance for Nanotechnology in Cancer program, the training component has been expanded to include Cancer Nanotechnology Training Centers (CNTCs) and Pathway to Independence Awards in Cancer Nanotechnology Research (K99/R00). The funded CNTCs will target graduate-student and post-doctoral researchers with broad backgrounds (in medicine, biology, and other health sciences as well as in the physical sciences, chemistry, and engineering). Although initiated in September 2010, both programs are expected to continue through August 2015. The program of multidisciplinary research education in cancer nanotechnology will primarily focus on mentored training, usually from multiple investigators in different disciplines, through laboratory-based research projects. In addition, centers will offer both short courses and workshops as well as outreach experiences. Given the challenges that senior post-doctoral fellows face in finishing projects and establishing themselves as independent investigators, the program has invested in funding several Pathway to Independence awardees. These trainees will benefit not only from their direct mentors but from the more informal mentoring and interaction at PI (principal investigator) meetings across the alliance.

NIST: As part of the expansion of the cold neutron measurement capability at the NIST Center for Neutron Research, a new neutron reflectometer is being constructed that will provide researchers with an unparalleled view of the nanoscale structure of multilayer systems—systems that are used, for example, in magnetic storage media. Using a novel neutron reflectometry instrument design, scientists will be able to characterize the detailed three-dimensional structure of numerous materials of technological relevance. The Center for Nanoscale Science and Technology in 2010 made over \$20 million of ARRA investments in new instrumentation that in 2011 will add new capabilities available for characterization of charge and matter transport in energy storage and conversion devices, focused ion beam nanofabrication and analysis, transmission electron microscopy, and optical lithography.

NSF: In 2012, NSF programs will support the training and education in nanoscale science and engineering of about 10,000 students and teachers. NSF is expanding the outreach of the National Center for Nanotechnology Applications and Career Knowledge (NACK, main node at The Pennsylvania State University) to other educational clusters and states.

USDA/NIFA: NIFA higher education programs will continue to support curriculum development, capacity building, and student fellowship and training in areas where nanotechnology has been emerging as an important topic.

Coordinated Activities with Other Agencies and Institutions Contributing to Goal 3

NIH and GRC: The NCI is organizing the first annual Gordon Research Conference (GRC) on Cancer Nanotechnology, which will be held in Waterville, ME, during the week of July 17–22, 2011. The Gordon Research Conferences have a long-standing tradition of excellence in hosting meetings whose topics are on the frontiers of science and whose speakers are leaders in their field. The GRC Cancer Nanotechnology meeting will bring together an outstanding and diverse group of scientists from the clinical, biological, and physical sciences as well as post-doctoral fellows and graduate students.

NIST and University of Maryland: In 2010 NIST awarded a five-year cooperative agreement totaling \$15 million to the University of Maryland, College Park, for a postdoctoral researcher and visiting fellow in the Measurement Science and Engineering Program at the NIST Center for Nanoscale Science and Technology. The program is providing new research opportunities for established U.S. industrial, university, and government scientists, along with training for the next generation of nanotechnologists through opportunities to work directly with CNST scientists and engineers on the development of nanoscale measurement and fabrication methods and technologies.

NSF and other NNI agencies: Cooperative programs by NSF, DOE (Sandia National Laboratories), NIST, DOD, and NIH provide support for student fellowship programs in various areas of nanotechnology.

Goal 4: Support responsible development of nanotechnology

The NNI has made significant progress towards realizing the goal of supporting responsible development of nanotechnology. Funding for nanotechnology-related EHS research continues to increase at a rate far in excess of the overall NNI budget growth rate, growing from \$35 million in 2005 to \$124 million in the 2012 request. This is only counting the narrowly defined *primary purpose* EHS R&D, although many other research programs also bear on EHS work. The NNI agencies have developed a comprehensive interagency strategy to move EHS investments forward effectively, in line with the roles and responsibilities of the respective agencies involved. The NNI also maintains a strong portfolio of research on ethical, legal, and other societal implications (ELSI) of nanotechnology, along with support for innovative approaches to nanotechnology education at all levels, from K–12 through graduate education and public outreach.

Individual Agency Contributions to Goal 4

DHS: DHS investments will continue to focus on the enhancement of security systems through application of advancements in nanoscience and related technology areas. All technology developments are evaluated through rigorous independent and operational testing programs to ensure safety and performance. DHS supports the interagency focus on safety and health concerns associated with advancing nanotechnology.

DOD: Although the DOD has not been the lead agency in the environmental, health, and safety areas of research, it has continued to support projects that relate to EHS issues in its mission portfolio. It is working closely with the NSET Subcommittee and its working groups, including the Nanotechnology Environmental and Health Implications Working Group, and is actively seeking additional collaborative opportunities in this area with other Federal agencies. DOD considers environmental, health, and safety issues to be intrinsic and pervasive in all nanotechnology research and in the responsible application of nanotechnology to products. As an example, the Air Force has developed compulsory guidelines for the safe handling of nanomaterials and for performing research associated with nanotechnology.¹² Furthermore, DOD has been investing in the development and use of nanotechnology and nanomaterials for the mitigation of hazards, both of the materials themselves and of other potentially bad actors in the environment. Two examples of such research follow.

- DOD projects are developing computational methods for predicting the physical and chemical properties of DNA-coated nanoparticles. These methods will replace current trial-and-error approaches and enable the *a priori* design of nanostructured materials with tailored characteristics, such as molecular recognition, catalysis, and signal transduction. Currently funded programs include the design of artificial membranes and synthetic receptors that will be used to construct robust sensors for chemical, biological, explosive, and radiological detection.
- DOD research in protection and hazard mitigation is developing the capability to not only detect and decontaminate a hazardous agent, but also to send a signal that it has done so. One project area that merges nanotechnology with information technology is the Smart Hazard Mitigation system. The goal is for this “smart” threat agent detection and mitigation system to be designed so that a sensor

¹² *Nanomaterial Safety Guidelines*, Air Force Research Laboratory/Applied Biotechnology Branch (AFRL/RHPB) Operating Instruction ESOH 111, 14 November 2007.

3. Progress Towards Achieving NNI Goals and Priorities

generates a response that acts to decontaminate, detoxify, or sequester the agent and then signals the response to an observer system. Nanotechnology is an enabler for this application because several approaches exist for nanoscale technologies to effectively decontaminate hazards at the molecular scale. For example, a porphyrin encapsulated in a metal-organic framework is designed to decontaminate a threat agent and also send a signal.

EPA: EPA's nanotechnology research is principally focused on supporting NNI Goal 4. The 2012 President's Budget request will further EPA's generation of decision-support information to promote the safe development, use, and disposal/recycling of products that contain manufactured nanoscale materials. EPA is investigating how nanomaterials behave in the environment, and how nanomaterial properties may be modified or exposure controls implemented to minimize and manage potential risks from products containing nanomaterials. Research using green chemistry and life-cycle assessment approaches will be conducted to inform a more sustainable approach to nanomaterial production. For example, EPA research will inform decisions on how to minimize inputs, including energy usage, during the production of nanomaterials. EPA is currently developing a more integrated, transdisciplinary approach to its research on chemicals and chemical safety. This approach will include research on nanomaterials and will help to inform how EPA identifies and addresses high-priority research needs related to the responsible development of nanotechnology.

EPA's Nanomaterial Research Strategy¹³ guides EPA's nanomaterial research. The strategy builds on and is consistent with the scientific needs identified the EPA Nanotechnology White Paper (2007)¹⁴ and the draft 2011 NNI nanoEHS Strategy.¹⁵

Since 2001, EPA has played a leading role in supporting research and setting research directions to develop beneficial environmental applications for nanotechnology as well as to understand the potential human health and environmental implications of nanotechnology. EPA has provided this leadership in its own research laboratories and centers, and through its Science to Achieve Results (STAR) grant program and contracts to small businesses under its Small Business Innovation Research program. The STAR and SBIR programs have resulted in the development of a cadre of highly skilled researchers with expertise in the area of environmental nanotechnology.

As the use of nanomaterials increases, EPA will continue to determine how to best leverage advances in nanotechnology to enhance public health and environmental protection, as well as improve scientific knowledge to understand and avoid any possible adverse impacts of nanomaterials on the environment. The goal is to foster technological advances that maximize benefits to society by minimizing environmental impacts.

FDA: FDA investments will continue to enable the agency to address questions related to the safety, effectiveness, and/or regulatory status of products that contain nanomaterials or otherwise involve the use of nanotechnology. For 2012, FDA will continue to conduct activities in PCA 7 (environment, health, and safety).

NIH: NIEHS has increased its investment in EHS research by starting a new program of grants in response to RFA ES-09-011: Engineered Nanomaterials: Linking Physical and Chemical Properties to Biology (U19) to improve our fundamental understanding of how physical and chemical properties of engineered nanomaterials influence interactions with biological systems and elicit biological responses. A

¹³ See <http://www.epa.gov/nanoscience>.

¹⁴ See <http://www.epa.gov/osa/pdfs/nanotech/epa-nanotechnology-whitepaper-0207.pdf>.

¹⁵ See <http://www.nano.gov/html/society/EHS.html>.

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contract has been established to provide comprehensive physicochemical characterization of nanomaterials for those grants by NCI's Nanotechnology Characterization Laboratory. An additional contract supports collaboration among NIEHS, NIBIB and NCI to establish the Nano Registry, a curated nanomaterials registry for information on biological and environmental interactions of well-characterized nanomaterials.

NIOSH: In 2011 and 2012, NIOSH will reorient its investment in nanotechnology research by enhancing the following programmatic areas:

Nanotoxicology and Risk Assessment: NIOSH scientists have published breakthrough results on the biologic behavior of carbon nanotubes, demonstrating pulmonary effects in laboratory animals and disruption of normal cell division in human epithelial cells. The potential health implications of this research for humans are unknown and will be a focus of investigation in 2011 and 2012. Areas of investigation include:

- Evaluating and identifying modes of biological action at the molecular level
- Evaluating various types of carbon nanotubes and other nanomaterials with high potential for commercialization that may not have been evaluated in previous studies or that have not been evaluated at the nanoscale
- Developing new lung deposition models to predict behavior of carbon nanotubes and fibers so that realistic risk estimates can be developed

Exposure Assessment and Controls: In 2010 and into early 2011, NIOSH increased its nanotechnology field research effort by adding two new elements: a field investigation focused on assessing worker exposure to carbonaceous nanomaterials; and a combined field and laboratory investigation of the effectiveness of engineering controls used to mitigate worker exposure to nanomaterials. Areas of investigation include:

- Increased effort to conduct worker exposure assessments with nanomaterials that have not been evaluated by the EHS community: nanoclays, nanocrystalline cellulose, nanosilver (various forms), metal and metal-oxide nanowires, high-volume use of quantum dots
- Focused research on developing air sampling and analytical detection methods for nanomaterials at various stages in their life cycles
- Continued research to develop and evaluate new instrumental methods of detecting airborne particles in the nanometer range and to demonstrate the concept of a personal, real-time nanoparticle detector

NIST: NIST is developing measurement tools to determine physico-chemical and toxicological properties of key engineered nanomaterials in relevant media (e.g., air, water, blood, tissue), enable detection of nanomaterials in such media, and assess transformations and release of these nanomaterials during manufacturing processes and from products throughout full product life cycles. In 2011 and 2012 NIST plans to develop transferable methods to characterize molecular adsorbates on nanomaterial surfaces, and develop measurement tools to determine the concentration of nanosilver and its ions in relevant media and products. NIST also plans to release reference materials important for EHS studies of engineered nanomaterials, including carbon nanotubes, titanium dioxide nanoparticles, and silver nanoparticles.

NSF: NSF supports research that focuses on analyzing implications of the next generations of nanotechnology products and productive processes, as well as public participation in nanotechnology-related activities, at the NSECs on societal dimensions at Arizona State University (ASU) and University of California Santa Barbara (UCSB).

NSF's Office of International Science and Engineering (OISE) will support a range of programs focused on catalyzing new international collaborations and engaging junior researchers in international research

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activities at an early stage in their careers. In addition, the Partnerships for International Research and Education (PIRE) program makes multimillion dollar awards designed to build strong international research and education partnerships, support research excellence through international collaboration, provide strong international research experiences for U.S. researchers, and foster the internationalization of U.S. institutions in science and engineering fields. Funding for nanotechnology activities will be done in competition with other projects. All current OISE programs support multiple projects in this area.

USDA/FS: For 2012, the Forest Service plans to broaden its nanotechnology research to investigate environmental, health, and safety issues and societal implications of renewable nanocellulose materials and their applications in downstream user industries.

USDA/NIFA: NIFA will support Goal 4 in the development of methods to evaluate the risk assessment of nanoparticles or the actual assessment of nanoparticles to ensure responsible development of nanotechnology applications. The AFRI program in Physical and Molecular Mechanisms of Food Contamination will seek proposals to elucidate the physical and molecular mechanisms of unintended engineered nanoparticles, food-borne pathogens or toxins, and chemical contaminants that may attach onto and internalize into fresh food crops and nuts; and develop detection methods to evaluate exposure to potential food safety hazards in fresh food crops. In addition, the funded research in the AFRI Emerging Food Safety Issues program area will characterize the toxicity, accumulation, and trophic transfer of nanomaterials by agricultural crops, including potential impacts on coexisting contaminants, and will explore potential risks to humans from exposure through food chain contamination.

USGS: The U.S. Geological Survey continues to work on understanding the fate and effects of nanoparticles in aquatic organisms.

Coordinated Activities with other Agencies and Institutions Contributing to Goal 4

DOD and other NNI agencies: DOD has been collaborating with the NSET Subcommittee's Nanotechnology Environmental and Health Implications Working Group and with other organizations in strategic planning and in mitigating the potential harmful effects of engineered nanomaterials and nanoscale processes.

The Army Missile Research, Development, and Engineering Center (AMRDEC) is currently collaborating with the Missile Defense Agency (MDA) on multiple efforts for weaponry safety and insensitive munitions utilizing nanomaterial-based propellants and for developing nanosensors for detecting radiation and temperature that offer high performance in extremely harsh environments. AMRDEC is also collaborating with MDA on research for weaponry life extension by developing carbon-fiber composites based on a nanoparticle polymer system in which self-healing and morphing properties restore damaged skins to their original condition.

EPA, NSF, USDA, CPSC, United Kingdom, OECD: EPA collaborates in both funding and conducting research with other Federal agencies, as well as international organizations, by issuing joint grant solicitations with other governments. Specifically, EPA's STAR Program has issued joint solicitations with the National Science Foundation and the U.S. Department of Agriculture. In addition, EPA, CPSC, and the United Kingdom awarded 6 grants in 2010 under a joint international solicitation. EPA researchers also coordinate and collaborate with other nations in the international testing program being conducted under the auspices of the OECD's Working Party on Manufactured Nanomaterials.

FDA, other NNI agencies, international organizations: FDA continues to foster and develop collaborative relationships with other Federal agencies through the NNI, as well as with sister regulatory

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agencies, international organizations, healthcare professionals, industry, consumers, and other stakeholders.

NIST, FDA, EPA, NIOSH, CPSC: Agencies are coordinating the development of benchmark data, measurement methods, and prototype reference materials for nanosilver for EHS assessments of products containing nanosilver.

NIST, EPA, NIOSH, CPSC, CDC, OSHA, industry: In 2011 agencies and industry representatives will hold a workshop focused on the release of nanomaterials from products, and agencies will hold a joint U.S.-EU workshop on nanotechnology-related EHS research.

NIST, NSF, DOE, EPA, IC, NIH, NIOSH, OSHA, USDA/FS: These agencies are working together on the NNI Signature Initiative on Sustainable Nanomanufacturing. Goal 4-related aspects of the initiative include development of nanomaterials and nanomanufacturing processes that are sustainable and safe by design, as well as analysis of the potential impacts of these materials and processes across their full life cycles. For example, in 2010 and 2011, NIOSH continued existing collaborations or created new formal working relationships with key NNI agencies and external collaborators to develop effective EHS risk management methods to support responsible development of nanomaterial manufacturing processes. NIOSH has also entered into formal collaborations with the NSF-funded Center for High-Rate Nanomanufacturing at Northeastern University and with other NNI research centers to develop risk management practices for nanomanufacturing and to explore incorporating “prevention through design” principles into life-cycle management of nanomaterials.

NIOSH, other NNI agencies, universities, industry: In 2010 and 2011, NIOSH continued existing collaborations or created new formal working relationships with key NNI agencies and external collaborators to develop effective EHS risk management methods to support responsible development of nanomaterial manufacturing processes:

- NIOSH entered into an Interagency Agreement with OSHA to investigate potential worker exposure in businesses manufacturing or using nanomaterials; evaluate control technologies and risk management methods; evaluate the use of control banding as a risk management method; and develop case studies on the application of “prevention through design” principles to nanomanufacturing processes.
- NIOSH renewed an Interagency Agreement with NIEHS/National Toxicology Program (new term of 2011–2013) to conduct visits to nanomanufacturing facilities and investigate potential worker exposure to nanomaterials that have not been previously evaluated. In the first three years of the agreement, NIOSH visited 24 sites and evaluated over ten different nanomaterials in processes ranging from basic research laboratories to high-volume production. Following every NIOSH site visit, the organization reassessed and issued a comprehensive report of findings, measurements, observations, and recommendations, all in support of developing good risk management practices.
- NIOSH has entered into two separate interagency agreements with the CPSC. In the first, NIOSH was able to characterize the aerosol released by a nanoscale TiO₂-based spray bathroom disinfectant and conduct animal toxicology testing of the product. The intent was to simulate consumer use, characterize the aerosol, and measure the exposure during use so CPSC could gain a better understanding of user exposure and possible risk. The second agreement focuses on determining bioavailability of nanosilver.
- During 2010 and into 2011, NIOSH and the Department of Defense created a framework memorandum for cooperation between the two agencies to evaluate exposures to nanomaterials, assess the effectiveness of controls, develop risk management procedures, investigate the use of control

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banding for some pilot projects, and demonstrate the effectiveness of using prevention through design on new nanomaterial processes.

- Collaborations with EPA have been more informal yet very productive. NIOSH participates with EPA on the Spray-Applied Nanomaterials work group. Briefings on NIOSH's workplace field efforts have been held to provide EPA with guidance on current practices being used by the nanomaterials business community.
- NIOSH has entered into a formal Memorandum of Understanding with the College of Nanoscale Science and Engineering (CNSE) at the State University of New York at Albany. Key program activities conducted under this agreement include collaboration with CNSE to develop effective risk management practices for nanomaterials used during semiconductor fabrication; development and evaluation of effective exposure mitigation practices during synthesis and pilot manufacturing of nanomaterials; and introducing "prevention through design" principles into a major capital project at CNSE. The agreement between NIOSH and CNSE creates collaboration opportunities with the SEMATECH consortium for the development of good risk management practices for the incorporation of nanomaterials in semiconductor fabrication and next-generation, nanomaterial-based photovoltaic manufacturing.
- NIOSH has established a formal working agreement with the Center for Multifunctional Polymer Nanomaterials and Devices (CMPND): Collaboration efforts with the center's member companies has focused on comprehensive evaluation of manufacturing processes, assessing worker exposures, evaluating exposure control methods and making recommendations for improvement, incorporating safe and sustainable design in facilities and processes, and providing an effective risk management framework suitable for small start-up businesses.
- Ongoing collaborations and a formal relationship between NIOSH and the NSF-funded Center for Biological and Environmental Nanotechnology (CBEN) and the International Council on Nanotechnology (ICON) have supported the continuing development of the GoodNanoGuide (<http://goodnanoguide.org>), a wiki-based collection of good risk management practices intended to support the EHS practitioner. The guide is global in scope and uses contributions from recognized EHS experts.

NSF, EPA, USDA/NIFA, EC: These NNI agencies collaborate with each other as well as internationally (e.g., with the European Commission, EC) in funding and coordinating research related to Goal 4, by supporting workshops and joint research and education programs. EPA, NSF, and NIFA issued a joint solicitation in 2010 entitled "Increasing Scientific Data on the Fate, Transport, and Behavior of Engineered Nanomaterials in Selected Environmental and Biological Matrices" in conjunction with an EC program solicitation. This has resulted in co-funded projects that increased the research investment intensity in the EHS issues relevant to the environment, agricultural production and food applications. NSF and EPA co-fund two Centers for Environmental Implications of Nanotechnology.

NSF, international research community: NSF has supported a project to embed humanists and social scientists in nanoscience and biotech laboratories around the world, providing a model for future integration of ethicists and social scientists into nanotechnology R&D laboratories. This work is facilitated by the NSF-sponsored ASU Nanotechnology in Society Center.

USDA/FS, industry, universities: The Forest Service is currently conducting nanotechnology research in areas of characterization, surface modification, and predictive modeling of renewable nanocrystalline cellulose in collaboration with private sector partners and Purdue University's Birck Nanotechnology

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Center. In 2012 the Forest Service plans to initiate collaborative research with several other academic institutions and private sector partners.

External Reviews of the NNI

Public Law 108-153 calls for periodic external reviews of the NNI by the National Research Council (NRC) of the National Academies and by the National Nanotechnology Advisory Panel (NNAP).

In December 2008 the National Research Council (NRC) of the National Academies released a report commissioned by the NNI to review its Strategy for Nanotechnology-Related Environmental, Health, and Safety Research.¹⁶ The NNI response to the NRC review is available at <http://www.nano.gov>.¹⁷ NNCO plans to commission a new NRC evaluation of the NNI in 2011.

The most recent comprehensive external review of the NNI was released in March 2010 by the President's Council of Advisors on Science and Technology (PCAST) in its role as the National Nanotechnology Advisory Panel.¹⁸ Input from these NRC and NNAP reviews has been incorporated into the 2011 NNI Strategic Plan and is being incorporated into an updated NNI strategy for nanotechnology-related environmental, health, and safety research, due to be released in early calendar year 2011. More details of NNI activities that correspond to the recommendations of these reviews are included elsewhere in this report.

Discussion of the recommendations from these studies and from other public and stakeholder input, and how the NNI is responding, is included in the 2011 updates to the NNI Strategic Plan and the NNI Strategy for Nanotechnology-Related EHS Research.

¹⁶ *Review of the Federal Strategy for Nanotechnology-Related Environmental, Health, and Safety Research*: http://www.nap.edu/catalog.php?record_id=12559.

¹⁷ http://www.nano.gov/NRC_Response_Letter_010509.pdf.

¹⁸ *Report to the President and Congress on the Third Assessment of the National Nanotechnology Initiative* (Executive Office of the President, Washington, DC, March, 2010; <http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-nni-report.pdf>).

APPENDIX A. GLOSSARY

Act	Public Law 108-153, the 21st Century Nanotechnology Research and Development Act
AF&PA	American Forest and Paper Association
AFRI	Agriculture and Food Research Initiative (USDA/NIFA)
Agencies	Departments, agencies, and commissions within the Executive Branch of U.S. Federal Government
ARO	Army Research Office (DOD)
ARPA-E	Advanced Research Projects Agency for Energy (DOE)
ARRA	American Recovery and Reinvestment Act
BIS	Bureau of Industry and Security (DOC)
CDC	Centers for Disease Control and Prevention (DHHS)
CEIN	Centers for Environmental Implications of Nanotechnology
CNST	Center for Nanoscale Science and Technology (DOC/NIST)
CNT	Carbon nanotube
CNTC	Cancer Nanotechnology Training Center (NCI)
CPSC	Consumer Product Safety Commission
CSREES	Cooperative State Research, Education, and Extension Service (USDA); replaced by the National Institute of Food and Agriculture (NIFA) in 2009
CoT	Committee on Technology of the NSTC
CR	Continuing resolution
DHS	Department of Homeland Security
DHHS	Department of Health and Human Services
DNI	Director of National Intelligence
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOEd	Department of Education
DOJ	Department of Justice
DOL	Department of Labor
DOS	Department of State
DOT	Department of Transportation
DOTreas	Department of the Treasury
DTRA	Defense Threat Reduction Agency (DOD)
EC	European Commission
EERE	[Office of] Energy Efficiency and Renewable Energy (DOE)
EHS	Environmental, health, and safety

Appendix A. Glossary

ENMs	engineered nanomaterials
EPA	Environmental Protection Agency
FDA	Food and Drug Administration (DHHS)
FHWA	Federal Highway Administration (DOT)
FS	Forest Service (USDA)
GIN	Global Issues in Nanotechnology Working Group of the NSET Subcommittee
IC	Intelligence Community
ICON	International Council on Nanotechnology
ISO	International Organization for Standardization
ITP	Industrial Technologies Program (DOE/EERE)
MOA	Memorandum of Agreement
MOU	Memorandum of Understanding
NASA	National Aeronautics and Space Administration
NCI	National Cancer Institute (DHHS/NIH)
NCL	Nanotechnology Characterization Laboratory (DHHS/NIH/NCI)
NCLT	Center for Learning and Teaching in Nanoscale Science and Engineering (NSF)
NCN	Network for Computational Nanotechnology (NSF)
NEHI	Nanotechnology Environmental and Health Implications Working Group of the NSET Subcommittee
NIBIB	National Institute of Biomedical Imaging and Bioengineering (DHHS/NIH)
NIEHS	National Institute of Environmental Health Sciences (DHHS/NIH)
NIFA	National Institute of Food and Agriculture (USDA, replacing CSREES Oct. 1, 2009)
NIH	National Institutes of Health (DHHS)
NILI	Nanotechnology Innovation and Liaison with Industry Working Group of the NSET Subcommittee
NIOSH	National Institute for Occupational Safety and Health (DHHS/CDC)
NISE	Nanoscale Informal Science Education (NSF-supported network)
NIST	National Institute of Standards and Technology (DOC)
NNAP	National Nanotechnology Advisory Panel
NNCO	National Nanotechnology Coordination Office
NNI	National Nanotechnology Initiative
NNIN	National Nanotechnology Infrastructure Network (NSF program)
NPEC	Nanotechnology Public Engagement and Communication Working Group of the NSET Subcommittee
NRC	Nuclear Regulatory Commission (also National Research Council of the National Academies)
NRO	National Reconnaissance Office (IC/DNI)
NSEC	Nanoscale Science and Engineering Centers (NSF program)
NSET	Nanoscale Science, Engineering, and Technology Subcommittee of the NSTC

Appendix A. Glossary

NSF	National Science Foundation
NSRC	Nanoscale Science Research Centers (DOE program)
NSTC	National Science and Technology Council
OECD	Organisation for Economic Co-operation and Development
OISE	Office of International Science and Engineering (NSF)
OMB	Office of Management and Budget (Executive Office of the President)
OSHA	Occupational Safety and Health Administration (DOL)
OSTP	Office of Science and Technology Policy (Executive Office of the President)
PCA	Program Component Area
PCAST	President's Council of Advisors on Science and Technology
PV	Photovoltaic(s)
QD	Quantum dot
SBIR	Small Business Innovation Research Program
SI	International System of Units (Le Système International d'Unités)
SNL	Sandia National Laboratories (DOE)
STAR	Science to Achieve Results (EPA)
STTR	Small Business Technology Transfer Research Program
TIP	Technology Innovation Program (NIST)
USDA	U.S. Department of Agriculture
USITC	U.S. International Trade Commission
USGS	U.S. Geological Survey (Department of the Interior)
USPTO	U.S. Patent and Trademark Office (DOC)
WHO	World Health Organization
WPMN	Working Party on Manufactured Nanomaterials (under the Chemicals Committee of the OECD)
WPN	Working Party on Nanotechnology (OECD)

APPENDIX B. CONTACT LIST

OSTP

Travis M. Earles
Assistant Director for Nanotechnology
Office of Science and Technology Policy
Executive Office of the President
New Executive Office Building
Washington, DC 20502
T: 202-456-6025
F: 202-456-6021
Travis_M._Earles@ostp.eop.gov

OMB

Irene Kariampuzha
Office of Management and Budget
Executive Office of the President
725 17th St., N.W.
Washington, DC 20503
T: 202-395-3535
F: 202-395-4652
Irene_Kariampuzha@omb.eop.gov

NNCO

Dr. E. Clayton Teague
Director and Coordinator for Standards
National Nanotechnology
Coordination Office
4201 Wilson Blvd.
Stafford II, Suite 405
Arlington, VA 22230
T: 703-292-4319
F: 703-292-9312
cteague@nnco.nano.gov

Dr. Sally Tinkle
Assistant Director and Coordinator for
Environment, Health, and Safety
Research
National Nanotechnology
Coordination Office
4201 Wilson Blvd.
Stafford II, Suite 405
Arlington, VA 22230
T: 703-292-4503
F: 703-292-9312
stinkle@nnco.nano.gov

CPSC

Dr. Mary Ann Danello
Associate Executive Director
Directorate for Health Sciences
Consumer Product Safety Commission
4330 East-West Highway, Suite 600
Bethesda, MD 20814
T: 301-504-7237
F: 301-504-0079
mdanello@cpsc.gov

Dr. Treye Thomas
Toxicologist
Office of Hazard Identification and
Reduction
Consumer Product Safety Commission
4330 East-West Highway, Suite 600
Bethesda, MD 20814
T: 301-504-7738
F: 301-504-0079
tthomas@cpsc.gov

DHS

Dr. Richard T. Lareau
Science and Technology Directorate
Department of Homeland Security
William J. Hughes Technical Center,
Bldg. 315
Atlantic City International Airport, NJ
08405
T: 609-813-2760
F: 609-383-1973
Richard.Lareau@dhs.gov

Dr. Eric J. Houser
Department of Homeland Security
Office of Research and Development
Science and Technology Directorate
1120 Vermont Ave., N.W.
Washington, DC 20005
T: 202-254-5366
eric.houser@dhs.gov

DNI

Richard D. Ridgley
Chief Scientist
Advanced Systems and Technology
Directorate
National Reconnaissance Office
14675 Lee Road
Chantilly, VA 20151
T: 703 808-3115
F: 703 808-2646
ridgleyr@nro.mil

DOC/BIS

Matt Borman
mborman@bis.doc.gov

DOD

Dr. Lewis Slotter
Associate Director, Materials &
Structures
Office of the Director, Defense Research
and Engineering
1777 N. Kent St Ste 9030
Arlington, VA 22209-2110
T: 703-588-7418
F: 703-696-2230
Lewis.Slotter@osd.mil

Dr. Akbar S. Khan
Senior Microbiologist & S&T Manager
Basic & Supporting Research Division
Defense Threat Reduction Agency
Fort Belvoir, VA 22060-6201
T: 703-767-3391
F: 703-767-1893
Akbar.Khan@dtra.mil

Dr. Gernot S. Pomrenke
Program Manager - Optoelectronics,
THz and Nanotechnology
AFOSR/NE
Directorate of Physics and Electronics
Air Force Office of Scientific Research
875 North Randolph Street
Suite 325, Rm. 3112
Arlington, VA 22203-1768
T: 703-696-8426
F: 703-696-8481
gernot.pomrenke@afosr.af.mil

Appendix B. Contact List

Dr. Eric Snow
Director, Institute for Nanoscience
Code 1100
Naval Research Laboratory
Washington DC 20375
T: 202-767-3261
F: 202-767-1821
snow@bloch.nrl.navy.mil

Dr. David M. Stepp
Chief, Materials Science Division
Army Research Office
AMSRL-RO-PM (Materials Science
Division)
P.O. Box 12211
Research Triangle Park, NC 27709
T: 919-549-4329
F: 919-549-4399
david.m.stepp@us.army.mil

DOE

Dr. Harriet Kung
Director, Office of Basic Energy
Sciences
Office of Science
U.S. Department of Energy
SC-22/GTN
1000 Independence Ave., S.W.
Washington, DC 20585
T: 301-903-3081
F: 301-903-6594
Harriet.Kung@science.doe.gov

Dr. Mihal E. Gross
Division of Scientific User Facilities
Office of Basic Energy Sciences
U.S. Department of Energy
SC-22.3/GTN
1000 Independence Avenue, S.W.
Washington, DC 20585-1290
T: 301-903-6827
F: 301-903-1690
Mihal.Gross@science.doe.gov

Dr. John C. Miller
Division of Chemical Sciences,
Geosciences, and Biosciences
Office of Basic Energy Sciences
U.S. Department of Energy
SC-22.1/GTN
1000 Independence Ave., S.W.
Washington, DC 20585
T: 301-903-5806
F: 301-903-4110
John.Miller@science.doe.gov

Dr. Ravi Prasher
Program Director
ARPA-E
U.S. Department of Energy
1000 Independence Ave. SW
Washington DC 20585
T: 202-287-6212
Ravi.Prasher@hq.doe.gov

Dr. Andrew R. Schwartz
Division of Materials Sciences and
Engineering
Office of Basic Energy Sciences
U.S. Department of Energy
SC-22.2/GTN
1000 Independence Avenue SW
Washington, DC 20585-1290
T: (301) 903-3535
F: (301) 903-9513
andrew.schwartz@science.doe.gov

Dr. Brian Valentine
Office of Industrial Technologies
U.S. Department of Energy
Headquarters Bldg., EE-2F
1000 Independence Avenue, S.W.
Washington, D.C. 20585-0121
T: 202-586-9741
F: 202-586-9234
Brian.Valentine@ee.doe.gov

Dr. Gideon Varga
U.S. Department of Energy
Industrial Technologies Program
EE-2F
1000 Independence Ave, SW
Washington, DC 20585
T: 202-586-0082
F: 202-586-9234
gideon.varga@ee.doe.gov

DOEd

Dr. Krishan Mathur
U.S. Department of Education
Office of Postsecondary Education
1990 K Street, N.W., #6144
Washington, DC 20006-8544
T: 202-502-7512
F: 202-502-7877
krish.mathur@ed.gov

DOJ

Joseph Heaps
Deputy Director, In-situ Thermal
Desorption Technology
Department of Justice
National Institute of Justice
Office of Science and Technology
810 7th Street, Rm. 7206
Washington, DC 20531
T: 202-305-1554
F: 202-305-9091
Joseph.Heaps@usdoj.gov

DOL/OSHA

Dr. Janet Carter
Senior Health Scientist
Department of Labor
Occupational Safety and Health
Administration
Room N3718
200 Constitution Ave., NW
Washington, DC 20210
T: 513-684-6030
F: 513-684-2630
Carter.Janet@dol.gov

DOS

Kenneth Hodgkins
Director
Office of Space & Advanced
Technology
U.S. Department of State
OES/SAT, SA-23
1990 K Street NW, Suite 410
Washington, DC 20006
T: 202-663-2398
F: 202-663-2402
HodgkinsKD@state.gov

Dr. Chris Cannizzaro
Physical Science Officer
Office of Space & Advanced
Technology
U.S. Department of State
OES/SAT, SA-23
1990 K Street NW, Suite 410
Washington, DC 20006
T: 202-663-2390
F: 202-663-2402
CannizzaroCM@state.gov

Appendix B. Contact List

DOT

Alasdair Cain
Research and Innovative Technology
Administration
Department of Transportation
1200 New Jersey Ave., S.E.
Washington, DC 20590
T: 202-366-0934
Alasdair.Cain@dot.gov

Dr. Jonathan Porter
Chief Scientist
Office of Research, Development, and
Technology
Federal Highway Administration
U.S. Department of Transportation
Turner-Fairbank Highway Research
Center
6300 Georgetown Pike
McLean VA 22101-2200
T: 202-493-3038
F: 202-493-3417
jonathan.porter@fhwa.dot.gov

DOTreas

Dr. John F. Bobalek
Program Manager
Office of Research and Technical
Support
Bureau of Engraving and Printing
Rm. 201-29A
14th and C Streets, S.W.
Washington, DC 20228-0001
T: 202-874-2109
F: 202-927-7415
John.Bobalek@bep.treas.gov

EPA

Jeff Morris
Acting National Program Director for
Nanotechnology
Office of Research and Development
Environmental Protection Agency
1200 Pennsylvania Ave., N.W.
Washington, D.C. 20460
T: 202-564-6756
F: 202-565-2494
Morris.Jeff@epa.gov

Dr. Nora F. Savage
National Center for Environmental
Research
Office of Research and Development
Mail Code 8722F
Environmental Protection Agency
1200 Pennsylvania Avenue, N.W.
Washington, DC 20460
T: 202-347-8104
F: 202-347-8142
Savage.Nora@epamail.epa.gov

Dr. Philip Sayre
Associate Director
Risk Assessment Division
Office of Pollution Prevention and
Toxics
Environmental Protection Agency
1200 Pennsylvania Ave., N.W.
Mail Code 7403M
Washington, DC 20460
T: 202-564-7673
F: 202-564-7450
sayre.phil@epa.gov

FDA

Carlos Peña, PhD, MS
Senior Science Policy Advisor
Office of the Commissioner
FDA
5600 Fishers Lane
HF-33, Room 14B08
Rockville, MD 20857
T: 301-796-8521
F: 301-827-3042
carlos.pena@fda.hhs.gov

NASA

Dr. Michael A. Meador
Chief, Polymers Branch
Structures and Materials Division
NASA Glenn Research Center
21000 Brookpark Road
Cleveland, OH 44135
T: 216-433-9518
F: 216-977-7132
Michael.A.Meador@nasa.gov

Dr. Minoo N. Dastoor
Chief Technologist, Innovative
Partnership Program Office
National Aeronautics and Space
Administration
NASA Headquarters, Rm. 6F80
Washington DC 20546-0001
T: 202-358-4518
F: 202-358-3878
mdastoor@mail.hq.nasa.gov

Dr. Meyya Meyyappan
National Aeronautics and Space
Administration
Ames Research Center
MS 229-3
Moffett Field, CA 94035
T: 650-604-2616
F: 650-604-5244
m.meyyappan@nasa.gov

NIH

Dr. Piotr Grodzinski
Program Director, Nanotechnology in
Cancer
Office of Technology and Industrial
Relations
Office of the Director
National Cancer Institute
National Institutes of Health
31 Center Drive, 10A52
Bethesda, MD 20892
T: 301-496-1550
F: 301-496-7807
grodzinp@mail.nih.gov

Dr. Lori Henderson
Program Director
National Institute of Biomedical
Imaging and Bioengineering
National Institutes of Health
Democracy Two, Suite 200, MSC 5469
6707 Democracy Blvd.
Bethesda, MD 20892-5469
T: 301-451-4778
F: 301-480-0679
hendersonlori@mail.nih.gov

Appendix B. Contact List

Dr. Jeffery A. Schloss
Program Director
Technology Development Coordination
National Human Genome Research
Institute
National Institutes of Health
Suite 4076, MSC 9305
5635 Fishers Lane
Bethesda, MD 20892-9305
T: 301-496-7531
F: 301-480-2770
jeff_schloss@nih.gov

NIH/OD

Dr. Lynn Hudson
Deputy Director
Office of Science Policy & Planning
National Institutes of Health
Office of the Director
Building 1 - Shannon Bldg, Rm. 218
1 Center Drive
Bethesda, MD 20892
T: 301-496-0786
F: 301-402-0280
HudsonL1@od.nih.gov

Dr. Nancy E. Miller
Senior Science Policy Analyst
Office of Science Policy and Planning
Office of the Director
National Institutes of Health
1 Center Drive
Bldg 1, Rm. 218
Bethesda, MD 20892
T: 301-594-7742
F: 301-402-0280
MILLERN@od1tm1.od.nih.gov

NIH/FIC

George Herrfurth
Multilateral Affairs Coordinator
Division of International Relations
Fogarty International Center
National Institutes of Health
Building 31, Rm. B2C11
Bethesda, MD 20892-2220
T: 301-402-1615
F: 301-480-3414
herrfurth@mail.nih.gov

NIH/NCI

Dr. Piotr Grodzinski
Program Director, Nanotechnology in
Cancer
Office of Technology and Industrial
Relations
Office of the Director
National Cancer Institute
National Institutes of Health
31 Center Drive, 10A52
Bethesda, MD. 20892
T: 301-496-1550
F: 301-496-7807
grodzinp@mail.nih.gov

Dr. Scott McNeil
Director, Nanotechnology
Characterization Laboratory
National Cancer Institute at Frederick
National Institutes of Health
P.O. Box B, Building 469
1050 Boyles Street
Frederick, MD 21702-1201
T: 301-846-6939
F: 301-846-6399
mcneils@ncicrf.gov

NIH/NHLBI

Dr. Denis Buxton
Basic and Early Translational Research
Program, DCVS
National Heart, Lung, and Blood
Institute
National Institutes of Health
6701 Rockledge Drive, Rm. 8216
Bethesda, MD 20817
T: 301-435-0513
F: 301-480-1454
BuxtonD@nhlbi.nih.gov

NIH/NIEHS

Dr. John R. Bucher
Associate Director
National Toxicology Program
National Institute of Environmental
Health Sciences
National Institutes of Health
P.O. Box 12233
Research Triangle Park, NC 27709
T: 919-541-4532
F: 919-541-4225
bucher@niehs.nih.gov

NIH/NIGMS

Dr. Catherine Lewis
Director, Division of Cell Biology and
Biophysics
National Institute of General Medical
Sciences
National Institutes of Health
45 Center Drive, Rm. MSC 6200
Bethesda, MD 20892-6200
T: 301-594-0828
F: 301-480-2004
catherine.lewis@nih.hhs.gov

NIOSH

Dr. Charles L. Geraci, Jr.
Coordinator, Nanotechnology Research
Center
National Institute for Occupational
Safety and Health
4676 Columbia Parkway
Cincinnati, OH 45226
T: 513-533-8339
CGeraci@cdc.gov

Dr. Vladimir V. Murashov
Special Assistant to the Director
National Institute for Occupational
Safety and Health
OD/NIOSH M/S-P12
395 E Street, S.W.
Suite 9200
Washington, DC 20201
T: 202-245-0668
F: 202-245-0628
vladimir.murashov@cdc.hhs.gov

NIST

Mark Bello
Public and Business Affairs Office
National Institute of Standards and
Technology
100 Bureau Drive, Stop 1070
Gaithersburg, MD 20899-1070
T: 301-975-3776
F: 301-926-1630
mark.bello@nist.gov

Dr. Jason Boehm
Director, Program Office
National Institute of Standards and
Technology
100 Bureau Drive, Stop 1060
Gaithersburg, MD 20899-1060
T: 301-975-8678
F: 301-216-0529
jason.boehm@nist.gov

Appendix B. Contact List

Dr. Ajit Jillavenkatesa
Program Office
National Institute of Standards and
Technology
100 Bureau Drive, Stop 1060
Gaithersburg, MD 20899-1060
T: 301-975-8519
F: 301-216-0529
ajit.jilla@nist.gov

Dr. Debra L. Kaiser
Chief, Ceramics Division
National Institute of Standards and
Technology
100 Bureau Drive, Stop 8520
Gaithersburg, MD 20899-8520
T: 301-975-6119
F: 301-975-5334
dkaiser@nist.gov

Dr. Robert Rudnitsky
National Institute of Standards and
Technology
100 Bureau Drive, Stop 6200
Gaithersburg, MD 20899-6200
T: 301-975-4699
T: 301-975-8026
robert.rudnitsky@nist.gov

Dr. Lloyd J. Whitman
Deputy Director, Center for Nanoscale
Science and Technology
National Institute of Standards and
Technology
100 Bureau Drive, Stop 6200
Gaithersburg, MD 20899-6200
T: 301-975-8002
F: 301-975-8026
whitman@nist.gov

NRC

Stuart Richards, Deputy Director
Division of Engineering
Office of Nuclear Regulatory Research
Nuclear Regulatory Commission
Washington, DC 20555-0001
T: 301-251-7616
Stuart.Richards@nrc.gov

NSF

Dr. Mihail C. Roco
Senior Advisor for Nanotechnology
National Science Foundation
Directorate for Engineering
4201 Wilson Blvd., Suite 505
Arlington, VA 22230
T: 703-292-8301
F: 703-292-9013
mroco@nsf.gov

Dr. Parag R Chitnis
Deputy Division Director
National Science Foundation
Directorate for Biological Sciences
4201 Wilson Blvd., Suite 605N
Arlington, VA 22230
T: 703-292-8440
F: 703-292-9061
pchitnis@nsf.gov

Dr. Ian Robertson
Director, Division of Materials Research
National Science Foundation
Directorate for Mathematical and
Physical Sciences
4201 Wilson Blvd., Suite 1065
Arlington, VA 22230
T: 703-292-4937
F: 703-292-9035
iroberts@nsf.gov

Dr. T. James Rudd
Program Manager, SBIR/STTR
Office of Industrial Innovation
National Science Foundation
4201 Wilson Blvd., Rm. 550
Arlington, VA 22230
T: 703-292-4759
F: 703-292-9057
tjrudd@nsf.gov

USDA/NIFA

Dr. Hongda Chen
National Program Leader, Bioprocess
Engineering/Nanotechnology
The National Institute of Food and
Agriculture
U.S. Department of Agriculture
1400 Independence Ave., S.W.
Mail Stop 2220
Washington, DC 20250-2220
T: 202-401-6497
F: 202-401-4888
HCHE@nifa.usda.gov

USDA/FS

Dr. Christopher D. Risbrudt
Director
Forest Products Laboratory
USDA Forest Service
One Gifford Pinchot Drive
Madison, WI 53726-2398
T: 608-231-9318
F: 608-231-9567
crisbrudt@fs.fed.us

Dr. Theodore H. Wegner
Assistant Director
Forest Products Laboratory
USDA Forest Service
One Gifford Pinchot Drive
Madison, WI 53726-2398
T: 608-231-9434
F: 608-231-9567
twegner@fs.fed.us

Dr. Robert Doudrick
Staff Director, Resource Use Science
USDA Forest Service
1400 Independence Ave., S.W.
Mailstop Code: 1114
Washington, DC 20250-1114
T: 703-605-4195
F: 703-605-5137
rdoudrick@fs.fed.us

Dr. World Nieh
National Program Leader, Forest
Products and Utilization
USDA Forest Service
1400 Independence Ave., S.W.
Mailstop Code: 1114
Washington, DC 20250-1114
T: 703-605-4197
F: 703-605-5137
wnieh@fs.fed.us

Dr. Howard Rosen
Resource Use Science
USDA Forest Service
1400 Independence Ave., S.W.
Mailstop Code: 1114
Washington, DC 20250-1114
T: 703-605-4196
F: 703-605-5137
hrosen@fs.fed.us

Appendix B. Contact List

USGS

Dr. Sarah Gerould
Bureau Program Coordinator,
Contaminant Biology Program
U.S. Geological Survey
Mail Stop 301 National Center
12201 Sunrise Valley Drive
Reston, VA 20192
T: 703-648-6895
F: 703-648-4238
sgerould@usgs.gov

USITC

Elizabeth R. Nesbitt
International Trade Analyst for
Biotechnology and Nanotechnology
Chemicals and Textiles Division
Office of Industries
U.S. International Trade Commission
500 E Street, S.W.
Washington, DC 20436
T: 202-205-3355
F: 202-205-3161
elizabeth.nesbitt@usitc.gov

USPTO

Charles Eloshway
Patent Attorney
Office of International Relations
Patent and Trademark Office
P.O. Box 1450
Alexandria, VA 22313
T: 571-272-9300
F: 571-273-0123
Charles.Eloshway@uspto.gov

Bruce Kisliuk
Assistant Deputy Commissioner for
Patent Operations
Mechanical Disciplines, TCs 3600 and
3700
Patent and Trademark Office
P.O. Box 1450
Alexandria, VA 22313
T: 571-272-5050
Bruce.Kisliuk@uspto.gov

Additional NNCO Staff Contacts

Marlowe Epstein
Acting Communications Director and
NILI Executive Secretary
National Nanotechnology
Coordination Office
4201 Wilson Blvd.
Stafford II, Suite 405
Arlington, VA 22230
T: 703-292-7128
F: 703-292-9312
mepstein@nnco.nano.gov

Liesl Heeter
IT Director and NEHI Executive
Secretary
National Nanotechnology
Coordination Office
4201 Wilson Blvd.
Stafford II, Suite 405
Arlington, VA 22230
T: 703-292-4533
F: 703-292-9312
lheeter@nnco.nano.gov

Geoffrey M. Holdridge
Policy Analyst and NSET Executive
Secretary
National Nanotechnology
Coordination Office
4201 Wilson Blvd.
Stafford II, Suite 405
Arlington, VA 22230
T: 703-292-4532
F: 703-292-9312
gholdrid@nnco.nano.gov

Jim Kadtko
Policy Analyst and GIN Executive
Secretary
National Nanotechnology
Coordination Office
4201 Wilson Blvd.
Stafford II, Suite 405
Arlington, VA 22230
T: 703-292-4399
F: 703-292-9312
jkadtko@nnco.nano.gov

Halyna Paikoush
Event Coordinator
National Nanotechnology
Coordination Office
4201 Wilson Blvd.
Stafford II, Suite 405
Arlington, VA 22230
T: 703-247-2176
F: 703-292-9312
hpaikoush@nnco.nano.gov

Diana Petreski
Office Manager
National Nanotechnology
Coordination Office
4201 Wilson Blvd.
Stafford II, Suite 405
Arlington, VA 22230
T: 703-292-8626
F: 703-292-9312
dpetreski@nnco.nano.gov

Kristin Roy
Webmaster and NPEC Executive
Secretary
National Nanotechnology
Coordination Office
4201 Wilson Blvd.
Stafford II, Suite 405
Arlington, VA 22230
T: 703-292-8906
F: 703-292-9312
kroy@nnco.nano.gov

National Science and Technology Council Committee on Technology

Subcommittee on Nanoscale Science, Engineering, and Technology

National Nanotechnology Coordination Office
4201 Wilson Blvd.
Stafford II, Rm. 405
Arlington, VA 22230

703-292-8626 phone
703-292-9312 fax

www.nano.gov