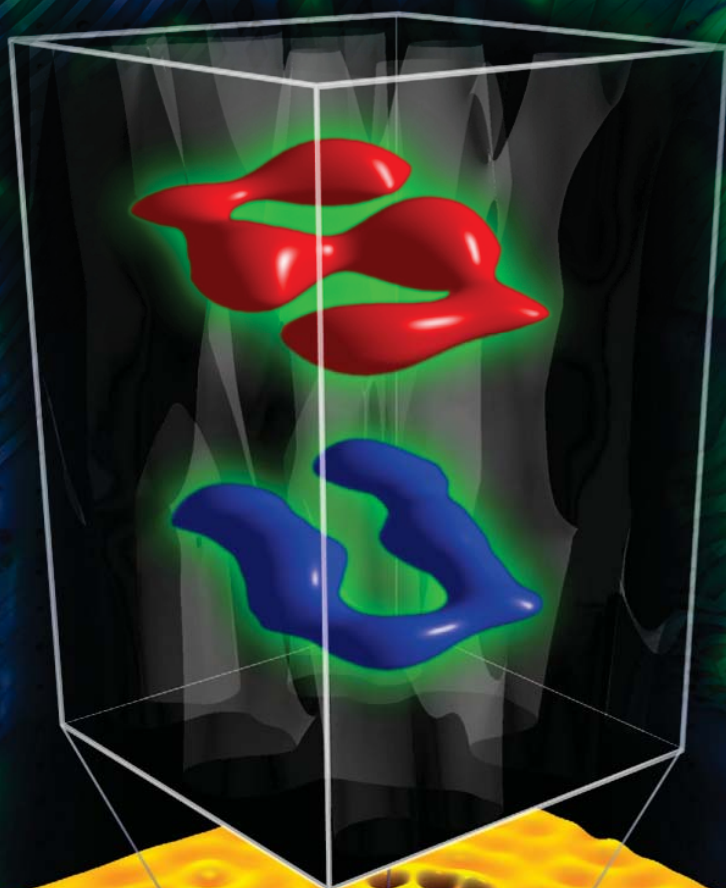


THE NATIONAL NANOTECHNOLOGY INITIATIVE

Research and Development Leading to a
Revolution in Technology and Industry

Supplement to the President's FY 2010 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. 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>.

About the Office of Science and Technology Policy

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 2010 Budget Request submitted to Congress on May 7, 2009. It gives a description of the activities underway in 2009 and planned for 2010 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 December 2007 and reports estimated investments for 2009 and requested investments for 2010 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

Central image: Atomically precise positioning of carbon monoxide molecules on a copper surface enables data storage with bits smaller than atoms. A molecular hologram, shown as dark dimples in the yellow surface, is fashioned one molecule at a time using a scanning tunneling microscope. By analogy to optical holography where density variations in an optical media constitute an optical hologram, here molecular position (density) constitutes the molecular hologram. When illuminated by the resident two-dimensional electron gas confined to the surface of the copper, a holographic image is created in the density of states as a function of three dimensions—energy, x-position, and y-position. This image is localized in the 5 nm by 5 nm central purple region devoid of molecules. The density of states information has in the examples shown been synthesized by positioning the molecules to form simple letters. Once encoded in this region, the information may be read out by scanning tunneling spectroscopy. Here, two pages of information, shown schematically as pages in a data cube, are retrieved by reading the density of electron states at two energy levels, one energy level shown as red and one as blue. Due to the quantum nature of the electron states used, these electronic objects have features smaller than anything possible to construct directly with atoms. This experiment shows that information can be stored at unprecedented densities by using electrons to encode data below the level of individual atoms (work funded by DOE BES, NSF, and ONR; courtesy of Hari Manoharan, Stanford University, <http://mota.stanford.edu>). Greenish portions of background: False-color scanning tunneling microscopy image revealing the atomic-scale electronic perturbations caused by a lattice defect in bilayer graphene (courtesy of Joseph Stroscio, National Institute of Standards and Technology, <http://cnst.nist.gov>).

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The National Nanotechnology Initiative

Research and Development Leading to a Revolution
in Technology and Industry



Supplement to the President's 2010 Budget

May 2009

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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EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
Washington, D.C. 20502

May 14, 2009

MEMBERS OF CONGRESS:

I am pleased to forward with this letter the annual report on the multi-agency National Nanotechnology Initiative (NNI). This Supplement to the President's Budget for Fiscal Year 2010 briefly describes the programs and coordinated activities taking place across all 25 of the agencies that are participating today in the NNI. Nanotechnology research and development (R&D) is inherently multidisciplinary and the rate of progress depends on the strong interagency coordination via the National Science and Technology Council to leverage expertise throughout the Federal Government and generate a whole greater than the sum of its parts.

The proposed NNI budget for Fiscal Year (FY) 2010 of \$1.64 billion will bring the cumulative investment since the inception of the NNI in FY 2001 to nearly \$12 billion. This sustained investment continues to advance our understanding of the unique phenomena and processes that occur at the nanometer scale and to expedite the responsible use of this knowledge to address national and global needs in high-impact opportunity areas such as energy, security, and public health. Participating agencies support this nanotechnology R&D consistent with the NNI Strategic Plan.

Along with its investment in the development and application of nanotechnology, the NNI continues to expand its activities to assess and address the potential health and environmental implications as well as societal and ethical concerns associated with this emerging technology. The requested budget increase for direct nanotechnology-related EHS research marks the initial impact of the *NNI Strategy for Nanotechnology-Related Environmental, Health, and Safety Research* released last year.

Nanotechnology R&D has already generated significant new products, tools, and processes. But it is the enormous potential of nanotechnology to lead to revolutionary, paradigm-shifting advances that warrants continued public and private investments. Taken as whole, the budget and collective leveraging efforts of the NNI reflect a longstanding commitment to broad-based support of closely-coordinated applications and implications research to enable responsible nanotechnology innovation in the United States that continues to set the pace for the rest of the world.

Thank you for your ongoing interest and support of this Federal initiative.

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 part.

John P. Holdren
Director

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1. INTRODUCTION AND OVERVIEW

Overview of the National Nanotechnology Initiative

The National Nanotechnology Initiative (NNI) is the U.S. Government interagency cross-cut program that coordinates Federal research and development activities in nanoscale science, engineering, and technology and related efforts among various participating agencies. Established in 2001,¹ the NNI is aimed at accelerating the discovery, development, and deployment of this technology. Currently the NNI involves the nanotechnology-related activities of 25 Federal agencies, 13 of which have budgets for nanotechnology research and development (R&D) for 2010 (see Table 1).

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 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; and develops, updates, and maintains the NNI website, <http://www.nano.gov>.

The NSET Subcommittee has established several working groups. These include 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.

The December 2007 NNI Strategic Plan² sets out a vision for the NNI: *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*. 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

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

² http://www.nano.gov/NNI_Strategic_Plan_2007.pdf.

1. Introduction and Overview

responsible development of nanotechnology. 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 categories in support of national goals and agency missions. NNI funding represents the sum of the funding allocated by each of the participating agencies. Each agency separately determines its budgets for nanotechnology R&D, in coordination with the Office of Management and Budget, the Office of Science and Technology Policy, and Congress. Thus, the NNI is an interagency budget crosscut in which participating agencies work closely with each other to create an integrated program through communication, coordination, and joint programs. This creates a synergy between individual agency programs in which the NNI is greater than the sum of its parts.

Purpose of this Report

This document provides supplemental information to the President's 2010 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 2008 and 2009, as well as those planned for in 2010. NNI budgets for 2008–2010 are presented by agency and PCA in Section 2 of this report. Information on the use of the Small Business Innovation Research Program (SBIR) and Small Business Technology Transfer Research Program (STTR) program funds to support nanotechnology research and commercialization activities, called for in P.L. 108-153, will be provided in a separate document after updated SBIR data become available later in 2009. Section 3 discusses activities that have been undertaken and progress that has been made toward achieving the 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 2009
Federal agencies with budgets dedicated to nanotechnology research and development
Cooperative State Research, Education, and Extension Service (CSREES, Department of Agriculture) ³ Department of Defense (DOD) Department of Energy (DOE) Department of Homeland Security (DHS) Department of Justice (DOJ) Department of Transportation (DOT) Environmental Protection Agency (EPA) 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 Institutes of Health (NIH, Department of Health and Human Services) National Institute of Standards and Technology (NIST, Department of Commerce) National Science Foundation (NSF)
Other participating agencies
Bureau of Industry and Security (BIS, Department of Commerce) Consumer Product Safety Commission (CPSC) Department of Education (DOEd) Department of Labor (DOL) Department of State (DOS) Department of the Treasury (DOTreas) Director of National Intelligence (DNI) Food and Drug Administration (FDA, Department of Health and Human Services) International Trade Commission (ITC) Nuclear Regulatory Commission (NRC) U.S. Geological Survey (USGS, Department of the Interior) U.S. Patent and Trademark Office (USPTO, Department of Commerce)

³ Section 7511 of the Food, Conservation, and Energy Act of 2008 (FCEA) establishes within the Department of Agriculture the National Institute of Food and Agriculture (NIFA) and transfers all authorities of the Cooperative State Research, Education, and Extension Service to NIFA not later than October 1, 2009.

2. NNI INVESTMENTS

Budget Summary

The 2010 Budget provides \$1.6 billion for the National Nanotechnology Initiative (NNI), reflecting steady growth in the NNI investment. This sustained major investment in nanotechnology research and development (R&D) across the Federal Government over the past ten fiscal years of the NNI reflects the broad support of the Administration and of Congress for this program. 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. The NNI remains focused on fulfilling the Federal role of supporting basic research, infrastructure development, and technology transfer, in the expectation that the resulting advances and capabilities will make important contributions to national priorities, with applications across a wide range of industries, including healthcare, electronics, aeronautics, agriculture and food, and energy. The NNI also is committed to implementing its comprehensive strategy for environmental, health, and safety (EHS) research.⁴ Increasing investments by NNI participating agencies in nanotechnology-related research since 2001 reflect a recognition of the potential for this research to support agency missions and responsibilities. The cumulative NNI investment since 2001, including the 2010 request, now totals almost \$12 billion. Cumulative investments in EHS research since 2005 now total over \$350 million. Cumulative investments in education and in research on ethical, legal, and other societal dimensions of nanotechnology since 2005 total over \$220 million.

The 2010 NNI budget supports nanoscale science and engineering R&D at 13 agencies. Agencies with the largest investments are:

- NSF (fundamental research across all disciplines of science and engineering)
- DOD (science and engineering research advancing defense and dual-use capabilities)
- 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)
- NIST (fundamental research and development of measurement and fabrication tools, analytical methodologies, and metrology for nanotechnology)

Other agencies investing in mission-related research are NASA, NIOSH, EPA, USDA (including both CSREES and FS), DHS, DOJ, and DOT (including the Federal Highway Administration, FHWA).

Table 2 shows NNI investments in 2008–2010 for Federal agencies with budgets and investments for nanotechnology R&D. Tables 3–6 list the investments by agency and by program component area (PCA). The program component areas shown in these tables are those outlined in the December 2007 NNI Strategic Plan,⁵ with nanotechnology-related EHS research reported in a separate PCA.

⁴ *Strategy for Nanotechnology-Related Environmental, Health, and Safety Research* (February 2008): http://www.nano.gov/NNI_EHS_Research_Strategy.pdf.

⁵ http://www.nano.gov/NNI_Strategic_Plan_2007.pdf, pp. 7–9.

2. NNI Investments

Table 2 NNI Budget, 2008–2010 (dollars in millions)				
	2008 Actual	2009 Estimate	2009 Recovery*	2010 Proposed
NSF	409	397	108	423
DOD**	460	464		379
DOE***	245	337	25	351
DHHS (NIH)****	305	311		326
DOC (NIST)	86	87	7	91
EPA	12	16		18
NASA	17	17		17
DHHS (NIOSH)	7	7		12
DHS	3	9		12
USDA (FS)	5	5		5
USDA (CSREES)	6	3		3
DOT (FHWA)	1	3		3
DOJ	0	0		0
TOTAL*****	1,554	1,657	140	1,640

* Based on preliminary allocations of the American Recovery and Reinvestment Act of 2009 (P.L. 111-5) appropriations. These figures may change. Other NNI agencies with ARRA funding, but not listed in the table, are in the process of determining their allocations.

** In Tables 2–4, the 2008 and 2009 DOD figures include Congressionally directed funding that is outside the NNI plan (\$117 million for 2009).

*** Funding levels for DOE include the Office of Science and the Office of Energy Efficiency and Renewable Energy.

**** NIH recently unveiled the Research, Condition, and Disease Categorization (RCDC) system, a new knowledge management system designed to provide more consistent and transparent information to the public about NIH research. The shift to the RCDC process of categorization changes the way individual research projects are assigned to categories. This change will result in some differences in total dollar amounts between the 2008 reports and those issued in previous years. Any difference, whether an increase or decrease in funding levels, does not necessarily reflect a change in the amount of money the NIH received from Congress or a change in the actual content of the NIH research portfolio. For more information about the RCDC process and some of the factors that might contribute to the differences between the previously reported and new RCDC-generated funding levels, please go to:

http://report.nih.gov/rcdc/category_process/Default.aspx and <http://report.nih.gov/rcdc/reasons/default.aspx>.

***** For Tables 2–6, totals may not add, due to rounding.

Key points about the 2009 and 2010 NNI investments

- Beyond the estimated \$1.66 billion in total NNI investments reported under the respective 2009 agency appropriations, an additional \$140 million has been provided for nanotechnology research and infrastructure investments in 2009 through the American Recovery and Reinvestment Act (ARRA) of 2009. Note that ARRA investments shown in Table 5 are not included in Table 4. Additional 2009 nanotechnology-related investments may be reported later, as agencies evaluate the results of funding opportunity announcements issued under ARRA.
- Research on fundamental nanoscale phenomena and processes remains the largest program component area, growing from \$478 million in 2008 to \$507 million in 2010. With additional funds provided under ARRA, the enacted funding for this PCA in 2009 totals \$548 million. Much of the increase for 2009 and 2010 stems from increased investments at DOE's Office of Science for basic research on energy applications of nanoscience, and at NSF.

2. NNI Investments

Table 3
Actual 2008 Agency Investments by Program Component Area
(dollars in millions)

	Fundamental Phenomena & Processes	Nanomaterials	Nanoscale Devices & Systems	Instrument Research, Metrology, & Standards	Nano-manufacturing	Major Research Facilities & Instr. Acquisition	Environment, Health, and Safety	Education & Societal Dimensions	NNI Total
NSF	154.3	72.9	44.6	21.8	20.7	29.1	29.2	35.9	408.6
DOD	200.2	73.9	137.9	8.1	7.8	28.7	3.8		460.4
DOE	50.3	72.4	4.7	16.3	6.8	91.1	2.6	0.5	244.7
DHHS (NIH)	47.4	43.1	159.5	5.3	0.7	36.0	11.9	0.6	304.5
DOC (NIST)	20.9	9.0	14.8	17.3	10.8	11.5	1.3		85.6
EPA	0.2	0.2	0.1				11.6		12.1
NASA	2.1	9.4	5.9						17.4
DHHS (NIOSH)							6.9		6.9
DHS		1.6	1.6						3.2
USDA (FS)	1.7	1.5	1.0	0.2	0.2				4.6
USDA (CSREES)	0.5	1.1	2.5		0.1		0.6	0.7	5.5
DOT (FHWA)	0.9								0.9
DOJ									0.1
TOTAL	478.5	285.1	372.7	69.0	47.1	196.4	67.9	37.7	1,554.4

Table 4
Estimated 2009 Agency Investments by Program Component Area
(dollars in millions)

	Fundamental Phenomena & Processes	Nanomaterials	Nanoscale Devices & Systems	Instrument Research, Metrology, & Standards	Nano-manufacturing	Major Research Facilities & Instr. Acquisition	Environment, Health, and Safety	Education & Societal Dimensions	NNI Total
NSF	146.4	74.6	42.3	17.6	21.9	34.4	27.9	32.1	397.2
DOD	192.6	76.6	131.8	8.9	25.3	25.2	3.7		464.1
DOE	96.1	88.5	8.3	31.7	4.9	103.8	3.1	0.5	336.9
DHHS (NIH)	48.4	44.5	164.3	5.5	0.7	37.1	10.2	0.6	311.3
DOC (NIST)	21.0	7.7	15.3	18.3	10.6	11.2	3.0		87.1
EPA	0.2	0.2	0.2				15.8		16.4
NASA	1.8	9.5	5.3						16.6
DHHS (NIOSH)							7.4		7.4
DHS		3.7	5.3		0.1				9.1
USDA (FS)	2.0	1.4	0.7	1.1	0.2				5.4
USDA (CSREES)	0.4	0.6	1.5		0.1		0.4	0.3	3.3
DOT (FHWA)		1.5	1.0						2.5
DOJ	0.1		0.1		0.1				0.3
TOTAL	509.0	308.8	376.1	83.1	63.9	211.7	71.5	33.5	1,657.6

2. NNI Investments

	Fundamental Phenomena & Processes	Nanomaterials	Nanoscale Devices & Systems	Instrument Research, & Metrology, & Standards	Nano-manufacturing	Major Research Facilities & Instr. Acquisition	Environment, Health, and Safety	Education & Societal Dimensions	NNI Total
NSF	38.5	27.7	9.2	3.4	3.2	17.7	2.7	5.4	107.8
DOE						25.0			25.0
DOC (NIST)						7.3			7.3
TOTAL	38.5	27.7	9.2	3.4	3.2	50.0	2.7	5.4	140.1

* Based on preliminary allocations of the American Recovery and Reinvestment Act of 2009 (P.L. 111-5) appropriations. These figures may change. Other NNI agencies with ARRA funding, but not listed in the table, are in the process of determining their allocations.

	Fundamental Phenomena & Processes	Nanomaterials	Nanoscale Devices & Systems	Instrument Research, & Metrology, & Standards	Nano-manufacturing	Major Research Facilities & Instr. Acquisition	Environment, Health, and Safety	Education & Societal Dimensions	NNI Total
NSF	154.7	80.4	43.8	18.5	22.5	38.5	29.9	34.7	423.0
DOD	174.8	61.6	100.6	4.6	14.2	21.0	1.7		378.5
DOE	103.2	82.4	12.8	35.1	4.9	109.6	2.9	0.5	351.4
DHHS (NIH)	48.8	45.2	169.3	5.5	0.7	38.2	17.3	0.6	325.6
DOC (NIST)	21.1	7.5	14.4	19.4	10.7	11.4	6.0		90.5
EPA	0.2	0.2	0.2				17.1		17.7
NASA	1.8	9.5	5.3						16.6
DHHS (NIOSH)							12.4		12.4
DHS		6.5	4.9		0.3				11.7
USDA (FS)	2.0	1.4	0.7	1.1	0.2				5.4
USDA (CSREES)	0.4	0.6	1.5		0.1		0.4	0.3	3.3
DOT (FHWA)		1.5	1.0						2.5
DOJ	0.1		0.1		0.1				0.4
TOTAL	507.1	296.8	354.6	84.2	53.7	218.7	87.7	36.1	1,639.0

- Other leading funding categories include the PCAs on nanoscale devices and systems (\$355 million in 2010) and nanomaterials (\$297 million in 2010). As the NNI's initial infrastructure investments mature, funding for the PCA on major research facilities and instrumentation acquisition has begun to level off (other than some increased funds provided under ARRA in 2009, which are being used to upgrade equipment and other facilities at DOE, NSF, and NIST user facilities).

2. NNI Investments

- Investments in environmental, health, and safety research continue to grow substantially from \$68 million in 2008 to a requested \$88 million for 2010. The increases are primarily targeted for leading and contributing agencies to address the prioritized research needs as identified in the NNI *Strategy for Nanotechnology-Related Environmental, Health, and Safety Research*,⁶ including instrumentation and fundamental characterization, exposure assessment, and human health implications. 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 continue to grow (from \$69 million in 2008 to \$84 million in 2010). Nanomanufacturing research investments are also growing (from \$47 million in 2008 to \$54 million in 2010, with a one-year increase to \$67 million in 2009, due in part to ARRA funding).
- Some of the largest percentage increases in nanotechnology-related funding for 2010 are at agencies such as NIOSH and EPA, which are increasing their funding for EHS research, and DHS, which has reexamined its investment portfolio and is ramping up some new efforts in nanotechnology (see below). NIH investments also continue to rise.

Changes in Balance of Investments by Program Component Area (PCA)⁷

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 for those agencies that are reporting significant changes for 2009 and 2010.

DHS: Significant changes in overall funding have occurred because some activities were not included in the previous-year estimates, and a number of program activities have been expanded due to planned program scope changes associated with transitioning of proof-of-concept efforts to prototype development and related technology transition efforts. 2010 programs are largely continuations of 2009 efforts, with limited new start proof-of-concept efforts beginning in 2010. The relative balance across PCAs from 2008–2010 is associated with regular program turnover and transition activities.

DOD: The Department of Defense continues to view nanotechnology as one of the enabling technologies that should receive the highest level of corporate attention and coordination as described in the 2007 Department of Defense Research & Engineering Strategy, which may be accessed online at http://www.dod.mil/ddre/doc/Strategic_Plan_Final.pdf. DOD 2010 plans include continued, approximately stable support for all PCAs except Societal Dimensions—Education and Ethical, Legal, and Other Societal Issues. The primary PCA emphasis is expected to be in Fundamental Nanoscale Phenomena and Processes, Nanoscale Devices and Systems, and Nanomaterials. New projects are awarded on a competitive basis, so the actual balance of investment may vary somewhat from expectations. The DOD is undertaking a comprehensive review of its nanotechnology programs and strategy and expects to provide a detailed report on its program and progress in November 2009.⁸

DOE: The predominant Department of Energy components of the National Nanotechnology Initiative are research programs and facilities supported by DOE's Office of Science. The investment in 2010 continues to support full operation of the five DOE Nanoscale Science Research Center (NSRC) user facilities (corresponding to the PCA for major research facilities and instrumentation acquisition) and an extensive

⁶ http://www.nano.gov/NNI_EHS_Research_Strategy.pdf.

⁷ Changes are as compared to NNI investments described in the NNI Supplement to the President's 2009 Budget, <http://www.nano.gov/html/res/pubs.html>.

⁸ The previous DOD nanotechnology report is available at <http://www.nano.gov/html/res/DefenseNano2007.pdf>.

2. NNI Investments

array of individual university grants and laboratory research programs. The Energy Frontier Research Centers, larger collaborative efforts in which a portion of the activity relates to nanoscale science, are also continued. (These constituted a substantial portion of the increase in DOE NNI funding in 2009 versus 2008.) Nanoscience funding increases in 2010 are due partly to small increases across all of these mechanisms, which include activities related to solar energy conversion, chemical imaging, nuclear energy, ultrafast science, instrumentation for characterization, and other areas. However, much of the increase in 2010 over 2009 results from the initiation of Energy Innovation Hubs focusing on electrical energy storage and solar fuels, in which it is anticipated that a fraction of the activity will be appropriately characterized as nanoscience. As a result of these changes, the DOE investment for 2010 includes a moderate increase under the Facilities and Instrumentation Acquisition PCA and considerably larger increases in the Fundamental Phenomena and Processes, Nanomaterials, and other PCAs.

DOT/FHWA: The continuation of work previously reported under the Fundamental Nanoscale Phenomena and Processes PCA will be reported under the Nanomaterials PCA beginning in 2009 to better reflect the nature of the work now being performed. In addition, the Federal Highway Administration plans to increase its overall nanotechnology investment in 2009 and will split this increase between the Nanomaterials PCA and the Nanoscale Devices and Systems PCA.

NSF: No significant changes. The balance of efforts among PCAs continues to support priority fundamental research, as well as all areas of relevance, including societal implications.

NIH: NIH expects to fund some additional nanotechnology-related projects in 2009 under ARRA and will provide estimates of the amounts as they become available, but it is including no ARRA funding in this report.

NIST: The President's 2010 Budget includes a \$3.5 million increase compared to 2009 in the NIST budget for research in nanotechnology. The NIST funding for EHS aspects of nanotechnology will increase from \$3.2 million in 2009 to \$6.2 million in 2010, to further the development of an accurate characterization framework needed by all Federal agencies for timely progress on this topic. Under this request, NIST will significantly expand its nanotechnology EHS activities through a coordinated initiative that leverages nanotechnology expertise and resources across its laboratories and facilities to develop analytical methods for quantifying the type and amount of nanomaterials in biological systems, the environment, and the workplace.

NIOSH: NIOSH continues to invest exclusively in the PCA on environment, health, and safety, corresponding to its lead role in conducting nanotechnology R&D related to worker health and safety, and in coordinating the NNI EHS research category on human and environmental exposure assessment. NIOSH conducts this work in close coordination with other agencies. This increased investment will support intramural and extramural projects that address critical research gaps related to potential occupational safety and health implications of nanotechnology and nanomaterials.

USDA/CSREES: USDA/CSREES will maintain its balanced investment by supporting research, development, education, and outreach activities in six of the eight PCAs (see Tables 3, 4, and 6 above, with PCA distributions). One noticeable change, though small in total dollars, is an increase in funding for both the Environment, Health and Safety PCA and the Educational and Societal Dimensions PCA. This is reflected in the 2008 actual and 2009 estimated spending, compared to what was reported in the NNI Supplement to the President's 2009 Budget, as well as in the 2010 request. The total dollar figures for the CSREES 2009 and 2010 nanotechnology budgets are slightly lower than those in the 2008 actual budget.

3. PROGRESS TOWARDS ACHIEVING NNI GOALS AND PRIORITIES

NNI Contributions to Administration Goals for the Nation

Nanotechnology cuts across a wide variety of scientific and engineering disciplines, and it has potentially revolutionary applications relevant to many national priorities and key industrial sectors, including aerospace, agriculture, biotechnology, homeland security and national defense, energy, environmental improvement, information technology, medicine, and transportation. The work of the NSET Subcommittee in coordinating the NNI contributes to many Administration goals. For example:

- **Economy.** The NNI, through the coordinated efforts of the NSET Subcommittee, is “[i]nvesting in the science, research, and technology that will lead to new medical breakthroughs, new discoveries, and entire new industries.”⁹ The NNI Vision, as set out in the December 2007 NNI Strategic Plan (p. 3), is “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.” Nanotechnology is expected to revolutionize traditional economic sectors (e.g., transportation and healthcare), as well as help to create the new high-technology industries of the future, where the United States can have comparative advantage over other countries. These new industries will create high-wage jobs for scientists, technicians, and manufacturing workers. “Transfer of new technologies into products for commercial and public benefit” is one of the NNI’s four overarching goals (see more details below). In keeping with this goal, the NNI Strategic Plan calls out ten examples of important national needs and major industry sectors on which nanotechnology could have an impact, including energy security, smarter computers, safe and affordable water, and early detection of life-threatening diseases. The plan also calls for coordinated efforts by the NSET Subcommittee member agencies to accelerate the development of these and other high-impact application areas by addressing critical research needs.
- **Energy and the Environment.** The NNI is expected to contribute to the Administration’s goal of developing a “comprehensive plan to invest in alternative and renewable energy, end our addiction to foreign oil, address the global climate crisis, and create millions of new jobs.”¹⁰ Potential contributions from nanotechnology towards this goal, and recommendations on the NNI research agenda to enable these contributions, are described in detail in two NSET Subcommittee-sponsored workshop reports:
 - *Nanoscience Research for Energy Needs* (http://www.nano.gov/nni_energy_rpt.pdf) outlines opportunities for major advancements in energy conversion, storage, and utilization, e.g., in developing inexpensive, high-efficiency photovoltaic cells and dramatically improved batteries.
 - *Nanotechnology and the Environment*, especially the sections on Applications and Implications (http://www.nano.gov/NNI_Nanotechnology_and_the_Environment.pdf), outlines opportunities for lower-cost environmental remediation through nanotechnology, as well as approaches for addressing potential EHS impacts of nanotechnology.
- **Technology.** The NNI also addresses several priorities listed under the Administration’s Technology agenda:
 - “Improve America’s Competitiveness”¹¹ by investing in the sciences and in university-based research; these are both key elements of the NSET Subcommittee’s strategy for the NNI.

⁹ From the Economy agenda on <http://whitehouse.gov>, accessed February 2009.

¹⁰ From the Energy & the Environment agenda on <http://whitehouse.gov>, accessed February 2009.

¹¹ This and the next two bullets from the Technology agenda on <http://whitehouse.gov>, accessed February 2009.

3. Progress Towards Achieving NNI Goals and Priorities

- “Prepare All our Children for the 21st Century Economy.” This goal is consistent with one of the four overarching goals outlined in the December 2007 NNI Strategic Plan of “develop[ing] and sustain[ing] educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology.” Part of the NNI vision from its inception has been that nanotechnology can inspire a new generation of Americans to take up careers in science and engineering. To this point, the NNI portfolio includes a wide range of formal and informal educational activities.
- “Employ Science, Technology, and Innovation to Solve Our Nation’s Most Pressing Problems.” See discussion about this above under “Economy” and “Energy and Environment.” The NNI portfolio includes large investments in nanotechnology research related to early detection and treatment of disease, including large, targeted programs at the National Cancer Institute, among others.
- National Defense. Toward the Administration’s objective to “invest in a 21st century military to maintain our conventional advantage while increasing our capacity to defeat the threats of tomorrow,”¹² the Department of Defense supports a large portfolio of nanotechnology basic research and applications development activities. Illustrations of the wide range of potential military applications of nanotechnology are included in a recently completed Air Force Research Laboratory brochure entitled *AFRL Nanoscience Technologies: Applications, Transitions and Innovations* (<http://www.nano.gov/AFRLNanobooklet.pdf>). DOD investments in these advanced technologies are essential to maintaining the technological edge that U.S. forces will continue to depend on in the future for success on the battlefield and for protecting our homeland security.

The NSET Subcommittee and the NNI continue to be models for effective coordination of interdisciplinary R&D that could be applied to these and many other areas of science and technology where research at the intersection of traditional disciplines offers great promise for major breakthroughs. The NNI strategy crafted by the NSET Subcommittee provides a particularly strong example of research at the intersection of the biological and physical sciences and engineering, for example.

The close coordination and cooperation through the NSET Subcommittee between the 25 participating agencies that has long characterized the NNI effectively leverages the mission-specific efforts of each agency and minimizes redundancies, thus making the most of the Federal investment in nanotechnology research and development in a way that substantially contributes to each of the above goals.

Activities Relating to the Four NNI Goals

As called for in the 21st Century Nanotechnology Research and Development Act, the 2007 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 2008 and 2009 and plans for 2010 are reported here in terms of how they promote progress toward the four NNI goals. Goal-related activities are in turn 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 three 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.*

¹² From the Defense agenda on <http://whitehouse.gov>, accessed February 2009.

3. Progress Towards Achieving NNI Goals and Priorities

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 the basic research discoveries into technologies and products for the benefit of our society and the nation's economy.

As indicated in the NNI Strategic Plan, 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 DHS Directorate for Science and Technology (S&T) is supporting nanotechnology research that will enable critical enhancements to homeland security applications in advanced threat detection systems and mitigation and blast protection materials and systems.

DOE: The Department of Energy's support of the National Nanotechnology Initiative continues to come primarily from the DOE's Office of Science through support of fundamental R&D, instrumentation, and construction and operation of major research facilities, as illustrated by the following recent developments and planned efforts:

- In 2009 DOE made five-year awards to initiate 46 new Energy Frontier Research Centers (EFRCs). These collaborative, multi-investigator, multi-institution research projects bring together interdisciplinary teams to focus on energy-relevant fundamental science.
- In 2009 DOE provided funding to expand single-investigator and small-group research projects in areas including solar energy, hydrogen fuel, energy storage, solid-state lighting, superconductivity, catalysis, advanced nuclear energy systems, geological carbon sequestration, clean combustion, materials under extreme conditions, and mid-scale instrumentation.
- In 2009 DOE stood up the Advanced Research Projects Agency—Energy to support the development of breakthrough energy technologies.
- Building on the success of DOE's three Bioenergy Research Centers, in 2010 DOE plans to initiate Energy Innovation Hubs to continue to encourage collaboration and team science and to connect the research labs to the industrial world.

While none of these efforts focus exclusively on nanoscience, it is expected that some portion of these activities will involve nanotechnology and that portion has been estimated in the budget figures provided.

NIST: NIST's research program in nanotechnology is addressing national needs in energy, the environment, healthcare, information technology security, manufacturing, and physical infrastructure, as illustrated by the following new developments:

- Nanolubricants that improve by nearly 300% the evaporator performance of chillers that cool buildings

3. Progress Towards Achieving NNI Goals and Priorities

- A new generation of “spintronic” nanoelectronic devices that promise to be 10 times faster and 100 times more energy-efficient than conventional electronics
- A research program to study the release of nanoparticles from nanocomposites used in building materials during their life cycles.
- A novel NIST microscopy technique, “through-focus scanning optical microscopy,” which can quickly and cheaply analyze nanoscale dimensions with nanoscale measurement sensitivity, with potential applications in nanomanufacturing, semiconductor process control, and biotechnology
- A radical new method of focusing a stream of ions down to a nanometer, with broad applications both for use in focused ion beam nanofabrication systems and for nondestructive imaging of nanoscale structures with finer resolution than possible with electron microscopes
- New programs to apply quantum phenomenon at the nanoscale, including single-photon counting and quantum coherence, enabling the development of revolutionary devices and sensors for quantum communications, national security, semiconductor device characterization, and astrophysics.

NRO: The National Reconnaissance Program (NRO) is supporting advanced nanotechnology R&D developments aimed to aid transition from the laboratory to system applications in the following areas:

- Improved solar cell performance with quantum dot inclusion in standard space solar cell processes
- Improved solar cell efficiency with inclusion of carbon nanotubes as the interface layers of a standard 3-layer solar cell
- Process and development techniques to weave carbon nanotube threads into conducting wires (e.g., fabrication of the “world’s first” USB cable using carbon nanotubes to replace copper conductors, resulting in improved performance)
- Carbon nanotube interconnects and vias, as demonstrated in a semiconductor foundry, to enable the replacement of aluminum and copper as the electronic pathways for charge carriers
- 16-kbit memories based on use of carbon nanotubes as nanoelectromechanical switches, and the first engineering model of 4-Mbit carbon nanotube memory with sufficiently high speed and low power consumption to potentially revolutionize memory applications in space vehicles

NSF: Major new efforts planned by NSF include the following:

- A planned new program on “Macromolecular, Supramolecular and Nanostructures.”
- The Powering the Planet (PP) Chemical Bonding Center (CBC), which will be funded at a level of \$4 million at the California Institute of Technology, to address the efficient, and ultimately economical, conversion of solar energy into stored chemical fuels. The efforts of the center focus on developing the components for a solar water-splitting system. The investigators are using novel nano- and micro- semiconductor structures to form new membranes capable of both efficient charge separation and proton management functions, which are needed for splitting water molecules to produce hydrogen and oxygen.
- Increased investment in using nanotechnology to address energy conversion and storage, “green” electronics, as well as water filtration.
- An initiative on “Beyond Moore’s Law Scaling” at the confluence between nanotechnology and information technology.

USDA/CSREES: CSREES’s Agriculture and Food Research Initiative (AFRI) nanotechnology research and development activity supports the agency’s mission and its strategic goals. It is combining its 2009 and

3. Progress Towards Achieving NNI Goals and Priorities

2010 nanotechnology funding, totaling approximately \$5 million, for a single solicitation in 2010. The program priorities remain broadly to include detection and intervention technologies for enhancing food safety and agricultural biosecurity; effective and safe delivery of bioactives in functional foods for improving human health and wellness; and product traceability, identity preservation, and tracking.

USDA/FS: The USDA Forest Service (FS) hosted a group of Canadian industry, federal, and Alberta provincial nanotechnology leaders to visit the United States in October 2008. During their visit, the Canadian group visited the forest products nanotechnology program at Pennsylvania State University (University Park, PA), the American Forest and Paper Association (AF&PA) Agenda 2020 Technology Alliance (Washington DC), the Chief of the Forest Service (Washington DC), the NNI/NSET NNCO office (Washington DC), and the USDA FS Forest Products Laboratory (Madison, WI). As a result of the visit, plans are being formulated to explore development of a joint United States-Canada program of precompetitive nanotechnology-based forest products research involving the Forest Service, the U.S. forest products industry as represented by the AF&PA Agenda 2020 Technology Alliance, and Canadian counterparts.

The 4th International Conference on Nanotechnology for the Forest Products Industry took place in St. Louis, MO, on June 25–27, 2008, with attendance by about 150 people, of whom about a third were from outside the United States. The 5th International Conference is being held in Edmonton, Alberta, Canada, June 24–26, 2009. Preliminary planning is underway for the 2010 6th International Conference, to be held in Europe, and the 2011 7th International Conference, to be held in the United States. The USDA Forest Service provides a co-chair for the conference, conference planning committee representatives, and research staff members who give conference presentations.

The USDA Forest Service is working with the AF&PA Agenda 2020 Technology Alliance-led industry Cooperative Board for Advancing Nanotechnology (CBAN) to identify and organize a core group of universities having expertise in both nanotechnology research and forest products research to work with Forest Service researchers. This group is being organized to advance a previously agreed-upon common agenda that meets the needs of industry and the Forest Service. The National Nanotechnology Initiative has been critical to advancing this public-private-university partnership.

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

NIH and the Chinese Academy of Sciences: The National Cancer Institute (NIH/NCI), the National Institute of Environmental Health Sciences (NIH/NIEHS), and the Chinese Academy of Sciences organized the “First Joint U.S.-China Symposium on Nanobiology and Nanomedicine” in Beijing, October 20–22, 2008. The goal of the symposium was to exchange research experiences and consider possible collaborations in the areas of cancer nanotechnology (prevention, detection, and treatment of the disease), and the effects of exposure to nanomaterials on the general public and the environment. In the United States, over \$1 billion/year of Federal support is dedicated to nanotechnology research and development. The Chinese government has recently established several nanotechnology research centers, including the National Center for Nanoscience and Technology in Beijing. In response to this rapidly maturing nanotechnology research base in China, this meeting and follow up conversations concerning possible venues of interactions should produce joint projects leveraging strengths of efforts in both countries and promote exchanges of researchers.

NIST, CPSC, and industry: NIST and the Consumer Product Safety Commission (CPSC) have agreed to jointly measure the release of nanoparticle flame retardants from upholstered furniture. NIST will lead the preparation of nanocomposite foams and the associated upholstery, and CPSC will assist with methodology

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and personnel. As a component of this effort, NIST has initiated a consortium with multiple companies from the nanotechnology and manufacturing industries on nanoparticle flame retardants for use in upholstered furniture (foam and barrier fabrics). The research, which will begin in 2009, will examine the fundamental mechanisms of nanoparticle flame-retardant action and determine the sustainability of this nanotechnology.

NIST, U.S. universities, and international institutions: NIST has established a series of collaborative research programs focused on the new area of quantum nanotechnology at Yale University, Stanford University, Cornell University, and the University of Maryland at College Park in the United States; and at Delft University (The Netherlands), Humboldt University (Germany), The University of Waterloo (Canada), The NRC (Canada), The Donostia International Physics Center (Spain), and The Nicolas Copernicus University (Poland) overseas.

NRO with DOD (USAF and DTRA): The National Reconnaissance Office, United States Air Force (USAF), and the Defense Threat Reduction Agency (DTRA) have initiated development of a carbon-nanotube-memory-based “domestic trusted source” high-speed, high-gate-count field programmable gate array (FPGA) for space and terrestrial applications with severe environmental constraints (extreme radiation, temperature, chemical, and biological challenges)

NRO with DOD (DTRA): These agencies have developed carbon-nanotube-based anode and cathode materials for use in lithium-ion batteries. Potential gains of 9x in mass reduction, 3x in capacity, and 3x in charging speed enable improved performance in both space and terrestrial (defense, automotive, computer, etc.) uses.

NSF, EPA: These agencies funded the second Center for Environmental Implications of Nanotechnology (CEIN) at Duke University in addition to the CEIN previously established at UCLA. Both those centers will be at the core of a nano-EHS academic network in the United States.

NSF, NIST, and the nanoelectronics industry: A series of workshops are planned by NSF, NIST, and industry for nanoelectronics beyond CMOS, including a grantees conference, one overview conference (INC6 in 2010), and other topical meetings.

NSF, DOE, and DOL: NSF, the Department of Education, and the Department of Labor coorganized a joint workshop and developed collaborative activities around several networks: the Network for Computational Nanotechnology (NCN), the National Nanotechnology Infrastructure Network (NNIN), the Nanoscale Informal Science Education Network (NISE Net), the National Center for Learning and Teaching in Nanoscale Science and Engineering (NCLT), and the Centers for Environmental Implications of Nanotechnology (CEIN).

NSF, DOD: These two agencies have planned a new initiative on “Quantum Information Science and Systems Engineering.”

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.

3. Progress Towards Achieving NNI Goals and Priorities

Individual Agency Contributions to Goal 2

DHS: The DHS S&T Directorate supports the transition of nanotechnology through academic and government laboratory partnerships with industry for incorporation of nanotechnology-based solutions into commercial systems, development and modification of COTS (commercial off-the-shelf) security technology, and development of advanced critical components for next-generation security systems. Specific investments include the development and application of nanostructured materials to trace explosives detection applications.

While many of the nanoscience breakthroughs occur in university settings, the rapid transition of these advancements to industry partners for critical component or system development is a crucial aspect of the timely enhancement of homeland security capabilities. While the DHS S&T Directorate is significantly investing in university research for the discovery and development of novel nanotechnology, most of these investments involve a commercial industry partnership in order to help focus and more rapidly transition any technical advancements into manufacturable devices and systems.

NIST: NIST's mission to develop measurement technologies in support of technology transfer includes significant nanotechnology investments. Examples include the following:

- The development of new reference cantilevers for commercial atomic force microscopes that enable quantitative nanoscale force and friction measurements needed to commercialize nanostructured materials and devices; a powerful technique to map nanoscale stress and strain, defects, and fatigue that will help to ensure the mechanical reliability of products manufactured from nanostructured materials; and cooperative research with industry to improve helium ion microscopy for nanometrology.
- In February 2008, NIST hosted the Second Tri-National Workshop on Standards for Nanotechnology, increasing mutual awareness and cooperation among U.S., Canadian, and Mexican delegates to international standards bodies.

NSF: NSF has planned a new model of Industry/University Cooperative Research Centers (I/UCRCs) focused on supporting fundamental nanoscale science and engineering projects proposed by industry groups.

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, NIOSH, NCI, 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 (ICSP), 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.

3. Progress Towards Achieving NNI Goals and Priorities

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.

DOE/EERE/ITP: The Department of Energy supports nanoscience technology transfer, industrial activity, and commercialization through the Office of Energy Efficiency and Renewable Energy (EERE) and its Industrial Technologies Program (ITP). In 2009, EERE is placing increased focus on improving the reliability of nanomaterial production and scale-up of manufacturing processes for utilizing nanomaterials in energy-related products and applications. Research teams from the DOE national laboratories and industry are developing and demonstrating technologies focused on nanocoatings, nanocatalysts, and nanocomposites. Examples range from erosion-resistant nanocoatings for gas turbines to nanoparticulate-based lubrication additives that reduce friction losses, to nanomaterial deposition technology for photovoltaic material production.

NIH and IEEE: The NIH in conjunction with the IEEE Society sponsored a nanomedicine workshop in April 2009 that outlined ongoing research in nanotechnology and industrial applications of nanomedicine.

NIST, USDA/FS, AF&PA Agenda 2020 Technology Alliance, University of Maryland, and industry: In May of 2008, NIST and the USDA Forest Service co-sponsored a workshop on Cross-Industry Issues in Nanomanufacturing, identifying common problems and solutions specific to nanotechnology, manufacturing processes, and performance of nanomaterials in commercial products within widely different industries, including aerospace, automotive, chemical, food, forest products, medical technology, pharmaceuticals, and semiconductors.

NRO with industry: NRO conducts nanotechnology developments with industry manufacturers in each of its nanotechnology R&D programs in order to foster a rapid transition from R&D to agency/industry dual-use. Industry partners have included Easton Sports, A123 Systems (battery), Spectrolab and Emcore (solar cells), ATK, Foster-Miller, Nantero, Lockheed Martin, Northrop Grumman, Nanocomp, Nanotech, Minnesota Wire, BAE Systems, Honeywell, and others.

NSF and other NNI agencies: The NSET Subcommittee's Nanomanufacturing, Industry Liaison, and Innovation (NILI) Working Group planned and conducted a workshop on Regional, State, and Local Initiatives in Nanotechnology on April 1–3, 2009. A report of the workshop is planned for 2009.

NSF, NIST, and semiconductor/electronics industry: NSF and NIST will continue and expand the partnership with the Nanoelectronics Research Initiative together with the Semiconductor Research Association, and will expand research and education to other long-term fundamental issues in nanoelectronics, photonics, and magnetism.

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. 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,

3. Progress Towards Achieving NNI Goals and Priorities

and other infrastructure for nanotechnology research, which was a key element of the original NNI strategy, is now largely complete.¹³

Individual Agency Contributions to Goal 3

DHS: The DHS S&T Directorate supports a range of nanotechnology development efforts at academic institutions at the graduate and postgraduate level, including several recently established centers of excellence. While these efforts are largely focused on development of breakthrough technology advancements, some aspects of these efforts also include problem-solving related to commercialization, such as, for example, scale-up of materials preparations.

NIST: The NIST advanced nanofabrication facility, the NanoFab, doubled its number of users in the past year, and in 2009 it will install approximately \$7 million of new nanofabrication tools.

NSF: NNIN will be provided \$10 million in ARRA funds to acquire advanced nanofabrication and characterization instrumentation and tools at several of its network sites, which will enable users to engage in state-of-the-art research projects. Availability of these funds will address the challenges the network has faced in maintaining its capital equipment base through acquisition of new instrumentation and replacement of aged or high-demand equipment.

NSF will recompile NCLT and NISE in 2009.

NSF will support the National Center for Nanotechnology Applications and Career Knowledge (NACK, The Pennsylvania State University) with national outreach to 2-year community and technical colleges and 4-year small universities and colleges. Several regional hubs for advanced nanotechnological education will be established in 2009 and 2010. NSF's Nanotechnology Undergraduate Education program will focus on nanoengineering and nanosystems with increased funding compared to 2008.

Coordinated Activities with Other Agencies and Institutions Contributing to Goal 3

NIST, DOE: State-of-the-art x-ray detector arrays developed by NIST now provide a series of instruments at the National Synchrotron Light Source at Brookhaven National Laboratory with the energy and depth sensitivity needed to determine the chemistry and structure of complex nanostructured materials and devices. These first-in-the-world capabilities have already enabled industry partners to design next-generation electronics materials and environmentally friendly automotive oil additives.

NIST, University of Maryland: NIST provides ongoing formal and informal opportunities for students and faculty from the University of Maryland to interact with NIST scientists and conduct nanotechnology research in NIST laboratories, and it jointly conducts outreach to the general non-science community and high school students, with an emphasis on disadvantaged or underrepresented groups.

NSF, DOE, and DOD: NSF's NCLT and NISE networks will provide shared activities and networking for educational activities with DOE and DOD.

USDA/CSREES, DOE: To promote awareness and utilization of the NNI research infrastructure, USDA/CSREES will conduct its nanotechnology grantees' annual meeting in conjunction with the DOE's joint Los Alamos Neutron Science Center and Center for Integrated Nanotechnologies (LANSCE/CINT)

¹³ 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).

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user conference in the fall of 2009 in Santa Fe, New Mexico. The CSREES grantees will have an opportunity to tour the DOE center facilities at Los Alamos and/or Albuquerque.

Goal 4: Support responsible development of nanotechnology

The NNI has made significant progress towards 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, from \$35 million in 2005 to \$88 million in the 2010 request. This is only counting the narrowly defined *primary purpose* EHS R&D. The NNI agencies have reached a strong consensus on a comprehensive strategy to move these 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 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

EPA: In support of its Nanomaterial Research Strategy,¹⁴ EPA has initiated a research program to understand which nanomaterials are most likely to enter the environment and how they move and transform within environmental media. This information will help the agency focus its human health and ecological effects research on those nanomaterials and pathways with the most potential for harmful human exposure. The program is already generating results. For example, EPA scientists demonstrated that making changes to specific nanoparticles, such as coating the particles with a layer of particular types of molecules, could change their toxicity. In another example, EPA-funded researchers at Rice University have produced iron oxide nanocrystals capable of removing toxic arsenic from drinking water. Results indicate that after two hours, iron oxide nanocrystals removed between 98.4 and 99.2 percent of the arsenic present. These results indicate nanotechnology has the potential to provide reliable, cost-effective approaches to remediate soil and water contaminated with toxic compounds.

DHS: The DHS S&T Directorate supports the responsible development of nanotechnology through the use of developmental and independent test and evaluation for all component and system technologies that incorporate advanced components.

FDA: The Food and Drug Administration's research program on nanoengineered materials reflects the need to build the knowledge base and experimental expertise necessary for regulation of products containing these materials. The results of this research will assist FDA in its mission to ensure the safety and efficacy of FDA-regulated products. These products include food, food additives, nutritional supplements, cosmetics, drugs, medical devices, and biologicals. Specifically, the work reflects the necessity for novel detection and characterization tools to support specific research on toxicity, biocompatibility, exposure assessment, formulation and suspension media affecting material properties, and product quality.

NIOSH: In 2009 and 2010 the National Institute for Occupational Safety and Health will focus its activities on (1) developing recommendations for controlling occupational exposure to fine and ultrafine titanium dioxide (TiO₂) and conducting research on improving sampling and analytical methods, determining the extent of workplace exposures, and controlling airborne exposures; (2) developing recommendations for controlling occupational exposures to carbon nanotubes and conducting research to address gaps in information on sampling, analysis, exposure assessment, instrumentation, and controls;

¹⁴ http://epa.gov/ncer/nano/publications/nano_strategy_012408.pdf

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(3) conducting research on how to identify categories of nanomaterials that can be distinguished on the basis of similar physicochemical properties; (4) conducting research to identify long-term health effects of carbon nanotubes; (5) conducting toxicological research on other nanomaterials likely to be commercially viable; and (6) conducting research on the explosive potential of various nanomaterials. In addition, NIOSH will continue providing guidance on engineering controls and personal protective equipment, and continue updating guidance documents for safe handling of nanomaterials.

NIST: NIST has developed new measurement technology to detect and characterize particles from 2 to 10 nanometers in diameter that are released by common kitchen appliances in abundant amounts and that greatly outnumber the previously detected, larger-size nanoparticles emitted by these appliances; NIST will continue to explore the production of such nanoparticles by indoor sources. Researchers showed that while engineered nanomaterials can be transferred up the lowest levels of the food chain from single-celled organisms to higher multicelled ones, the amount transferred is relatively low, with no evidence of the nanomaterials concentrating in the higher-level organisms.

NIST has also developed new techniques to purify carbon nanotubes and is applying this method to create carbon nanotube reference materials that enable uniform testing for EHS and commercial applications. Using these specimens, NIST made the first measurements of length-dependent cell uptake of nanotubes—a key step in determining their potential hazard to biological systems.

NSF: New efforts by NSF toward this goal are as follows:

- NSF will provide supplements to its Nanoscale Science and Engineering Centers (NSECs) for nanotechnology-related EHS projects on a competitive basis.
- The Nanotechnology in Society (NIS) Network will extend its national and international network.
- NSF will support activities of a new Society for the Study of Nanoscience and Emerging Technologies with an international network of researchers, students, stakeholders, and policymakers.
- A study is being conducted to assess and compare the capability of research centers in nanotechnology and other emerging technologies to integrate broader societal considerations and social sciences into their work. This study is coordinated with a European effort using the same methodology.
- NSF's NIS, NISE and NCLT networks are developing educational outreach resources addressing nanotechnology-related EHS issues.
- NSF continues to provide support for two centers for the study of societal dimensions of nanotechnology. Work at these centers helps build infrastructure for incorporating societal concerns directly into nanoscale science and engineering.

Coordinated Activities with other Agencies and Institutions Contributing to Goal 4

NNI member agencies, OECD: The DOS has chaired the OECD WPN to advise on emerging policy issues in science, technology, and innovation related to the responsible development and use of nanotechnology. EPA has chaired the OECD Working Party on Manufactured Nanomaterials (WPMN), which is leading an international effort by the 30 OECD member nations and other nonmember nations and organizations to coordinate and collaborate on approaches for better understanding the environmental, health, and safety impacts and the benefits of nanotechnology. In 2008, the WPMN embarked on a cooperative international program to conduct testing on fourteen nanomaterials types across 59 environmental endpoints. The EPA is leading the U.S. effort to sponsor the testing of many of these materials.

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EPA, NSF, NIH/NIEHS, NIOSH, USDA/CSREES, and EC: EPA is partnering with sister agencies in the United Kingdom and will jointly fund two consortia between U.S. and United Kingdom research institutions. In addition, EPA is leading another interagency solicitation with NSF, NIH/NIEHS, NIOSH, and USDA/CSREES, all in coordination with the European Commission, focused on exposure and safety research data for engineered nanomaterials.

EPA, NSF, NIH/NIEHS, NIOSH, and DOE: Since 2004 EPA's STAR (Science to Achieve Results) grants program has coordinated interagency requests for applications; agencies involved have included NSF, NIEHS, NIOSH, and DOE. The fourth joint research solicitation by EPA's STAR program was issued in 2007. The solicitation was a collaboration between the EPA, NSF, and DOE; over 130 research proposals were received. EPA awarded 15 grants, NSF awarded 6 grants, and DOE awarded 1 grant and made several awards to DOE laboratories. Individual grant awards totaled approximately \$9 million. In addition, EPA recently awarded \$2 million to study fate and transport in biological systems as part of an NIEHS-led request for applications.

NIH/NIEHS, NIST, NIH/NCI, FDA, NIOSH, Oregon Nanoscience and Microtechnologies Institute, and ASTM International: NIH/NIEHS in collaboration with NIST held a workshop on Enabling Standards for Nanomaterial Characterization on October 8–9, 2008, at NIST in Gaithersburg, Maryland. The goal was to address the urgent need to accelerate standards development at the prestandards stage.

NIH/NCI, NIH/NIEHS, and NIST: These agencies organized and held a one-day workshop at NIST on October 10, 2008, to establish an International Collaboration for NanoEHS Informatics aimed at developing a federated database system. The collaboration seeks to establish a global resource of knowledge on nanomaterial characteristics and their biological interactions that can be systematically queried from multiple sites within an interoperable, federated system of databases. Discussions between NIH's National Institute for Biomedical Imaging and BioEngineering (NIBIB) and NIEHS institutes are also underway to define possible venues that address these and other related nanobioinformatic needs of the community.

NIH/NIEHS, EPA, and University of Massachusetts: These institutions and other academicians are co-sponsoring the International Conference on the Environmental Implications and Applications of Nanotechnology in June 2009 in Amherst, MA. The conference will provide a valuable forum for scientists, regulators, and policymakers from academia, government, and industry to interact and share new knowledge on the health and environmental impacts of nanotechnology, green nanotechnology, and new environmental applications, and to help direct future research and regulatory needs. The conference will discuss global health and safety issues surrounding engineered nanoparticles and nanotechnologies, especially in connection with occupational and environmental health, and will provide insights into the latest research results and actions to assure the safety and thereby the future success of nanotechnologies.

NIOSH, all other NEHI member agencies: NIOSH led the organizing committee within the Nanotechnology Environmental and Health Implications (NEHI) Working Group to organize the NNI Health and Environmental Exposure Assessment workshop that took place February 24–25, 2009. The workshop aimed to provide an open forum to facilitate effective communication among stakeholders about progress achieved in the human and environmental exposure assessment research category and about the path forward for addressing research needs in this category.

NIOSH, OECD: NIOSH will continue its leadership role in the OECD WPMN steering group on "Cooperation on Exposure Measurement and Exposure Mitigation." Within this activity NIOSH is leading the development of globally harmonized protocols for nanomaterial emission assessment, guidance for the use of personal protective equipment, and guidance for the use of engineering controls. NIOSH will also

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continue conducting experiments and contributing data for carbon nanotubes (CNTs) and nanostructured titanium dioxide (TiO₂), silver (Ag), and cerium dioxide (CeO₂) to the OECD WPMN sponsorship program for safety testing of nanomaterials.

NIOSH, World Health Organization (WHO): NIOSH will continue developing and disseminating best practices globally for working with nanomaterials in collaborations with occupational safety and health institutions and coordinating activities led by WHO collaborating centers in the nanotechnology area.

NIOSH, International Alliance for NanoEHS Harmonization (IANH): NIOSH will participate in the IANH round-robin testing of toxicological techniques to ensure their reproducibility and to facilitate development of globally harmonized approaches to safety testing.

NIOSH, International Council on Nanotechnology (ICON): NIOSH will continue active participation in ICON's "Nano Good Practices Wiki" project, which aims to develop and maintain global best occupational practices for the safe handling of nanomaterials, utilizing a collaborative wiki-software platform.

NIOSH, CPSC: Under an interagency agreement signed in 2008, NIOSH collaborates with the Consumer Product Safety Commission on studying exposure potential resulting from use of selected spray applications utilizing nanomaterials.

NIST, NIH, FDA, and NIOSH: New measurements and reference nanomaterials are being developed for commercial and biomedical applications. With support from NIH and technical input from the FDA and NIOSH, NIST established the first gold nanoparticle reference materials in 2008 (<https://srmors.nist.gov>). Coordinated development of reference materials will continue through 2010 for nanoparticulate titanium dioxide and silicon dioxide, both of which are widely used in personal care, automotive coatings, paints, and catalysis products.

NIST, NIOSH: Using prototype single-walled carbon nanotube reference material from NIST, NIOSH and NIST are collaborating on measuring toxicological effects important to characterizing potential worker exposure to such nanomaterials.

NSF, EPA: To ensure that nanotechnology is developed in a responsible manner, the National Science Foundation and the Environmental Protection Agency have awarded approximately \$38 million over five years (starting in September 2008) to establish two Centers for the Environmental Implications of Nanotechnology (CEIN). The CEINs are an important addition to the NNI and will build on NSF's Center for Biological and Environmental Technologies (CBET) and EPA's STAR grants on nanotechnology. Led by the University of California at Los Angeles and Duke University, the CEINs will study how nanomaterials interact with the environment and human health, resulting in better risk assessment and mitigation strategies. Each center will work as a network, connected to multiple research organizations, industry, and government agencies, and will emphasize interdisciplinary research and education.

USDA/CSREES: The CSREES Nanoscale Science and Engineering for Agriculture and Food Program (within AFRI) will continue to support competitive grants to assess and analyze the perceptions and acceptance of nanotechnology applications to food and agriculture and nanotechnology-based products by the general public, agriculture producers and processing industry, and other stakeholders, using appropriate social science tools. This effort started in 2008 and has funded three projects. One of them was awarded to Cornell University, which has produced six "radio blast" pieces for the EarthSky program through interviewing experts about nanotechnology applications and implications to agriculture and food systems.

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The program is estimated to reach out to audiences of more than 14 million in both the United States and other countries. Another grant funded a research project at the Michigan State University to address public perceptions of emerging applications of nanotechnologies in food and agricultural production, titled “Public Perceptions of Agrifood Nanotechnologies: Using Extension to Assess and Link Stakeholder Knowledge with Public Policies.” The project seeks to develop within the Cooperative Extension System the capacity to train extension educators on (1) what nanotechnologies are and what their current and emerging applications are throughout the agrifood system, so that extension agents can speak knowledgeably about these matters with their clientele; and (2) develop in the agents the social science research skills for documenting key public perceptions as revealed through extension agent-client interaction, and for translating/transferring this information to agrifood policy organizations through delivery systems that increase the likelihood of information utilization. The long-term goal of this project is to inform and enhance socially responsive policies for agrifood nanotechnologies at national, state, and population-specific levels.

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.

The last comprehensive National Academies review, *A Matter of Size: Triennial Review of the National Nanotechnology Initiative*,¹⁵ was released in December 2006. The NNI Supplement to the President’s FY 2009 Budget¹⁶ includes an overview of the recommendations of that study and how the NNI participating agencies are responding to them. In December 2008 the National Research Council (NRC) of the National Academies released a new report commissioned by the NNI to review its strategy for nanotechnology-related environmental, health, and safety research.¹⁷ The NNI response to the NRC review is available at <http://www.nano.gov>.¹⁸

The most recent comprehensive external review of the NNI was released in April of 2008 by the President’s Council of Advisors on Science and Technology (PCAST) in its role as the National Nanotechnology Advisory Panel.¹⁹ The NNI Supplement to the President’s FY 2009 Budget includes a review of the findings from the PCAST report.

The NSET Subcommittee and member agencies incorporate the findings of these external reviews into the planning and implementation of ongoing NNI programs. More details of NNI activities that correspond to the recommendations of these reviews are included elsewhere in this report.

¹⁵ http://books.nap.edu/catalog.php?record_id=11752

¹⁶ http://www.nano.gov/NNI_09Budget.pdf, pp. 36–37.

¹⁷ *Review of the Federal Strategy for Nanotechnology-Related Environmental, Health, and Safety Research*: http://www.nap.edu/catalog.php?record_id=12559.

¹⁸ http://www.nano.gov/NRC_Response_Letter_010509.pdf.

¹⁹ *The National Nanotechnology Initiative: Second Assessment and Recommendations of the National Nanotechnology Advisory Panel*: http://ostp.gov/galleries/PCAST/PCAST_NNAP_NNI_Assessment_2008.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/CSREES)
Agencies	Departments, agencies, and commissions within the Executive Branch of U.S. Federal Government
ARO	Army Research Office (DOD)
ARRA	American Recovery and Reinvestment Act
BIS	Bureau of Industry and Security (DOC)
CBAN	Cooperative Board for Advancing Nanotechnology
CDC	Centers for Disease Control and Prevention
CEIN	Centers for Environmental Implications of Nanotechnology
CNST	Center for Nanoscale Science and Technology (DOC/NIST)
CNT	Carbon nanotube
CPSC	Consumer Product Safety Commission
CSREES	Cooperative State Research, Education, and Extension Service (USDA)
CT	Committee on Technology of the NSTC
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
EPA	Environmental Protection Agency
FDA	Food and Drug Administration (DHHS)

Appendix A. Glossary

FHWA	Federal Highway Administration (DOT)
FS	Forest Service (USDA)
GIN	Global Issues in Nanotechnology (NSET Subcommittee working group)
ICON	International Council on Nanotechnology
ISO	International Organization for Standardization
ITC	International Trade Commission
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/Centers for Disease Control and Prevention)
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
NSEC	Nanoscale Science and Engineering Centers (NSF program)
NSET	Nanoscale Science, Engineering, and Technology Subcommittee of the NSTC
NSF	National Science Foundation
NSRC	Nanoscale Science Research Centers (DOE program)
NSTC	National Science and Technology Council
NTP	National Toxicology Program (DHHS)
OECD	Organisation for Economic Co-operation and Development

Appendix A. Glossary

OMB	Office of Management and Budget (Executive Office of the President)
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
SBIR	Small Business Innovation Research Program
STAR	Science to Achieve Results (EPA)
STTR	Small Business Technology Transfer Research Program
USGS	U.S. Geological Survey (Department of the Interior)
USPTO	U.S. Patent and Trademark Office (DOC)
USDA	U.S. Department of Agriculture
WHO	World Health Organization
WPMN	Working Party on Manufactured Nanomaterials (under the Chemicals Committee of the OECD)
WPN	Working Party on Nanotechnology (OECD)

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