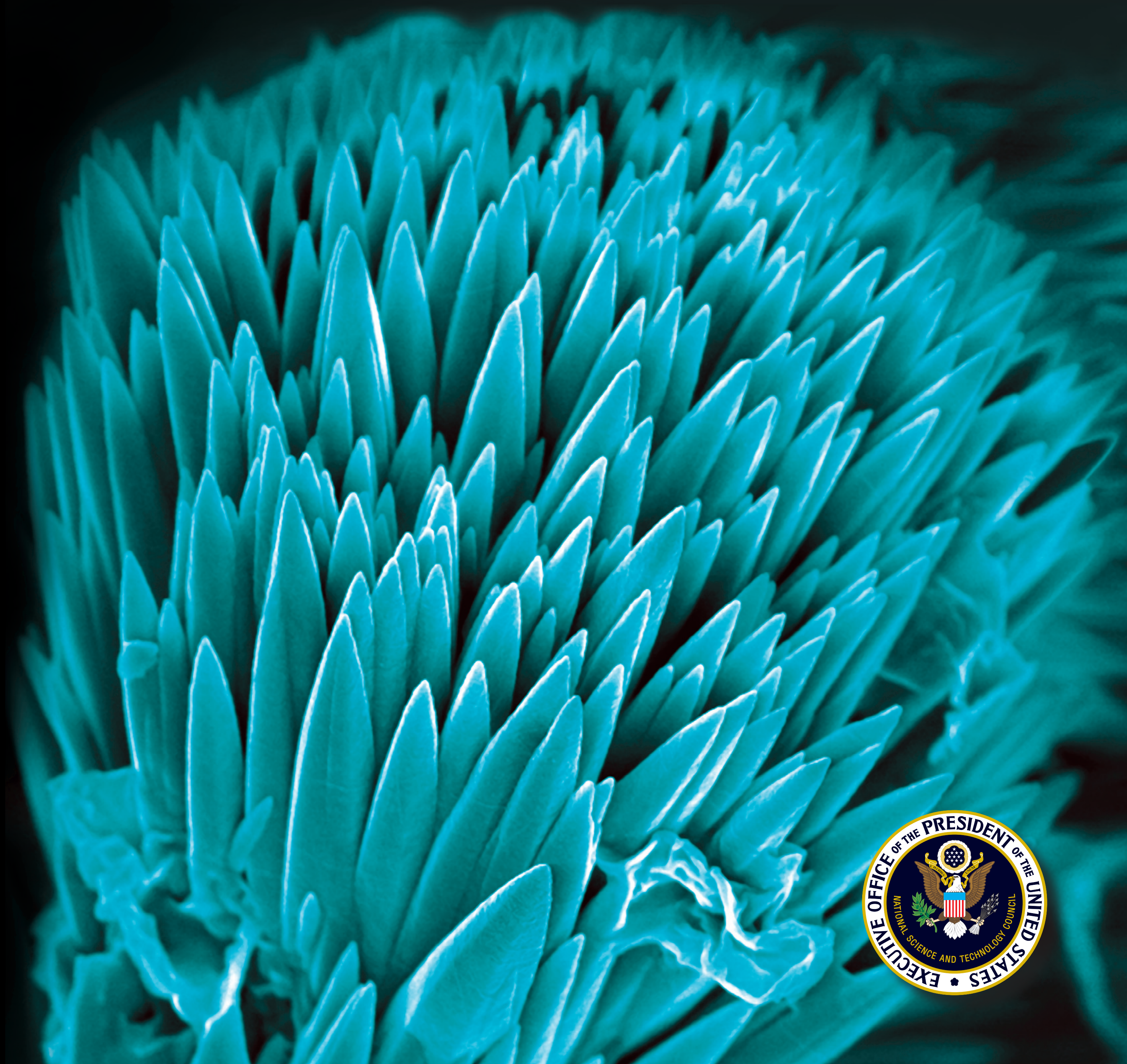
THE NATIONAL NANOTECHNOLOGY INITIATIVE

Supplement to the President's 2013 Budget



EXECUTIVE OFFICE OF THE PRESIDENT OF THE UNITED STATES

NATIONAL SCIENCE AND TECHNOLOGY COUNCIL

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 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 www.ostp.gov/.

About this document

This document is a supplement to the President's 2013 Budget Request submitted to Congress on February 13, 2012. It gives a description of the activities underway in 2011 and 2012 and planned for 2013 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 2011, estimated investments for 2012, and requested investments for 2013 by Program Component Area (PCA), as called for under the provisions of the 21st Century Nanotechnology Research and Development Act of 2003 (Public Law 108-153, 15 USC §7501). The report also addresses the requirement for Department of Defense reporting on its nanotechnology investments, per 10 USC §2358. Additional information regarding the NNI is available on the NNI website at www.nano.gov.

About the cover

A metal-organic framework (MOF) composed of zinc nitrate and 2,5-dihydroxy terephthalic acid was imaged at 10,000-times magnification as part of a study to understand how nanoporous frameworks can be created and modified to improve gas capture properties. The MOF is part of a new series of materials developed by Pacific Northwest National Laboratory (PNNL) that have tiny "cages" that can be used to trap carbon dioxide. The crystals in the cages have a diameter of about 25 nanometers. The cages themselves consist of metal ions linked together with organic ligands forming a porous network that traps gas molecules. The unique molecules have two to three times the capacity for carbon dioxide uptake as conventional solvents and appear to have an extremely high preference for carbon dioxide over other gases. The surface area of one gram of this molecule is equivalent to about that of a football field. This image (in false color) was captured using a focused ion beam scanning electron microscope at the Environmental Molecular Sciences Laboratory (EMSL), a Department of Energy national scientific user facility. (Work funded by the Department of Energy's Office of Fossil Energy and Office of Basic Energy Sciences; courtesy of Bruce Arey, EMSL, www.emsl.pnnl.gov, and Carlos A. Fernandez and Praveen Thallapally, PNNL, www.pnnl.gov.)

Cover and book design

Cover design is by Kathy Tresnak of Koncept, Inc. Book design is by staff of the National Nanotechnology Coordination Office (NNCO).

Copyright information

This document is a work of the U.S. Government and is in the public domain (see 17 USC §105). Subject to stipulations below, it may be distributed and copied, with acknowledgement to NNCO. Copyrights to graphics included in this document are reserved by original copyright holders or their assignees and are used here under the Government's license and by permission. Requests to use any images must be made to the provider identified in the image credits, or to NNCO if no provider is identified.

Printed in the United States of America, 2012.

SUPPLEMENT TO THE PRESIDENT'S BUDGET FOR FISCAL YEAR 2013

THE NATIONAL NANOTECHNOLOGY INITIATIVE

Research and Development Leading to a Revolution in Technology and Industry

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

February 2012

Report prepared by

NATIONAL SCIENCE AND TECHNOLOGY COUNCIL

COMMITTEE ON TECHNOLOGY (CoT)

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

CoT Chair: **Tom Power**, Office of Science and Technology Policy*
CoT Executive Secretary: **Pedro Espina**, Office of Science and Technology Policy

NSET Subcommittee Co-Chairs:
Altaf H. Carim, Office of Science and Technology Policy
Lewis Sloter, Department of Defense

NSET Subcommittee Executive Secretary:
Geoffrey M. Holdridge, National Nanotechnology Coordination Office

National Nanotechnology Coordination Office Deputy Director / Acting Director, and Coordinator for Environmental, Health, and Safety Research:
Sally Tinkle

* ***Former CoT Chair:*** **Aneesh Chopra**

Department and Agency Representatives to the NSET Subcommittee

Office of Science and Technology Policy (OSTP)
Altaf H. Carim

Office of Management and Budget (OMB)
Celinda Marsh

Agricultural Research Service (ARS/USDA)
Robert Fireovid

Bureau of Industry and Security (BIS/DOC)
Kelly Gardner

Consumer Product Safety Commission (CPSC)
Mary Ann Danello
Treye A. Thomas

Department of Defense (DOD)
Khershed Cooper
Akbar Khan
Gernot S. Pomrenke
Lewis Sloter
David M. Stepp

Department of Education (DOEd)
Peirce Hammond
Krishan Mathur

Department of Energy (DOE)
Harriet Kung
Mihal E. Gross
John C. Miller
Ravi Prasher
Andrew R. Schwartz
Brian G. Valentine

Department of Homeland Security (DHS)
Richard T. Lareau
Eric J. Houser

Department of Justice (DOJ)
Joseph Heaps

Department of Labor (DOL)
Janet Carter

Department of State (DOS)
Ken Hodgkins
Chris Cannizzaro

Department of Transportation (DOT)
Alasdair Cain
Jonathan R. Porter

Department of the Treasury (DOTreas)
John F. Bobalek

Director of National Intelligence (DNI)
Richard Ridgley

Environmental Protection Agency (EPA)
Nora F. Savage
Philip G. Sayre

Food and Drug Administration (FDA/DHHS)
Carlos Peña

Forest Service (FS/USDA)
World L.-S. Nieh
Theodore H. Wegner

National Aeronautics and Space Administration (NASA)
Michael A. Meador

National Institute of Food and Agriculture (NIFA/USDA)
Hongda Chen

National Institute for Occupational Safety and Health (NIOSH/CDC/DHHS)
Charles L. Geraci
Vladimir V. Murashov

National Institute of Standards and Technology (NIST/DOC)
Lloyd J. Whitman

National Institutes of Health (NIH/DHHS)
Piotr Grodzinski
Lori Henderson

National Science Foundation (NSF)
Mihail C. Roco
Parag R. Chitnis
Thomas Rieker
Grace J. Wang

Nuclear Regulatory Commission (NRC)
Stuart Richards

U.S. Geological Survey (USGS)
Sarah Gerould

U.S. International Trade Commission (USITC)
Elizabeth R. Nesbitt

U.S. Patent and Trademark Office (USPTO/DOC)
David R. Gerk
Bruce Kisliuk

EXECUTIVE OFFICE OF THE PRESIDENT
NATIONAL SCIENCE AND TECHNOLOGY COUNCIL
WASHINGTON, D.C. 20502

February 15, 2012

Members of Congress:

I am pleased to forward this annual report on the multi-agency National Nanotechnology Initiative (NNI), in the form of the NNI Supplement to the President's Budget for Fiscal Year 2013. This document summarizes the programs and coordinated activities taking place across the many departments and agencies participating today in the NNI – an initiative that has been a leading model of Federal science and technology coordination for nearly a dozen years. 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 2013 of nearly $1.8 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*. Signature initiatives within the NNI represent areas of particular focus – solar energy, next-generation electronics, and sustainable manufacturing – in which participating agencies have identified key opportunities and plan more intensive programmatic collaboration. NNI activities are also very relevant to, and support, the *Advanced Manufacturing Partnership* –a national effort directed towards ensuring American leadership in this critical area– and the *Materials Genome Initiative* –a drive to accelerate the design and deployment of advanced materials– as well as other Federal R&D initiatives.

The NNI investment sustains vital support for fundamental, ground-breaking R&D; research infrastructure, including world-class centers, networks, and user facilities; and education and training programs that collectively constitute a major wellspring of innovation in the United States. It also 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 innovation enabled by nanotechnology and other emerging technologies. Now more than ever, the Nation's economic growth and global competitiveness depend on it. The NNI reflects a longstanding commitment to broad-based pursuit 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. I look forward to your support as we work together to achieve that vision.

Sincerely,

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

TABLE OF CONTENTS

1. Introduction and Overview

Overview of the National Nanotechnology Initiative

The National Nanotechnology Initiative (NNI), established in 2001,[1] is a U.S. Government research and development (R&D) initiative involving 26 agencies working together toward the shared and 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*."[2] The combined, coordinated efforts of these agencies have accelerated discovery, development, and deployment of nanotechnology to benefit agency missions in service of the broader national interest. The 26 agencies participating in the NNI are shown in Table 1; 15 of these agencies have specific budgets for nanotechnology R&D for 2013.

The NNI 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 progress for the initiative. The NSET Subcommittee is composed of representatives from participating agencies. A listing of official NSET Subcommittee members is provided at the front of this report, and 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, including the preparation of multiagency planning, budget, and assessment documents; develops, updates, and maintains the NNI website 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 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 Communications (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] **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] *The National Nanotechnology Initiative Strategic Plan* (NSTC, Washington DC, 2011; nano.gov/nnistrategicplan2011.pdf), p. 4.

The 2011 NNI Strategic Plan sets out the vision for the NNI stated above and 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
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 R&D investment categories. These Program Component Areas (PCAs) include research and development activities that will contribute to one or more of the NNI 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

The NNI R&D investment is also guided by the 2011 NNI Environmental, Health, and Safety Research Strategy.[3] The strategy supports all four NNI goals but is most closely aligned with NNI Goal 4 and PCAs 7 and 8.

The NNI funding represents the sum of the nanotechnology-related funds allocated by each of the participating agencies (the NNI budget crosscut). Each agency separately determines its budget for nanotechnology R&D in coordination with the Office of Management and Budget (OMB), the Office of Science and Technology Policy (OSTP), and Congress. The NNI agencies participating in the budget crosscut work closely with each other to create an integrated scientific program. This enhanced communication, facilitated through the NSET Subcommittee and its working groups, has led to interagency 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 2013 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, 15 USC §7501). The report also addresses the requirement for Department of Defense reporting on its nanotechnology investments, per 10 USC §2358. In particular, the report summarizes NNI programmatic activities for 2011 and 2012, as well as those currently planned for 2013. NNI budgets for

---

[3] *The National Nanotechnology Initiative Environmental, Health, and Safety Research Strategy* (NSTC, Washington DC, 2011; http://nano.gov/sites/default/files/pub_resource/nni_2011_ehs_research_strategy.pdf.

2011–2013 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. 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 from external reviews of the NNI and how their recommendations are being addressed, are presented in Section 3.

Table 1: List of Federal Agencies Participating in the NNI During 2012
Federal agencies with budgets dedicated to nanotechnology research and development
Agricultural Research Service (ARS, U.S. Department of Agriculture, USDA) Consumer Product Safety Commission (CPSC) Department of Defense (DOD) Department of Energy (DOE) Department of Homeland Security (DHS) 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, DHHS) Forest Service (FS, USDA) National Aeronautics and Space Administration (NASA) National Institute for Occupational Safety and Health (NIOSH, Centers for Disease Control and Prevention, CDC/DHHS) National Institute of Food and Agriculture (NIFA, USDA) National Institute of Standards and Technology (NIST, Department of Commerce, DOC) National Institutes of Health (NIH, DHHS) National Science Foundation (NSF)
Other participating agencies
Bureau of Industry and Security (BIS, DOC) Department of Education (DOEd) Department of Justice (DOJ) 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, DOC)

2. NNI INVESTMENTS

Budget Summary

The President's 2013 Budget provides nearly $1.8 billion for the National Nanotechnology Initiative (NNI), a sustained investment in support of the President's priorities and innovation strategy. Cumulatively totaling almost $18 billion since the inception of the NNI in 2001 (including the 2013 request), this support reflects nanotechnology's potential to significantly improve our fundamental understanding and control of matter at the nanoscale and to translate that knowledge into solutions for critical national issues. NNI research efforts are guided by two strategic documents developed by the Nanoscale Science, Engineering, and Technology (NSET) Subcommittee of the National Science and Technology Council (NSTC), the 2011 NNI Strategic Plan (nano.gov/node/581) and the 2011 NNI Environmental, Health, and Safety Research Strategy (nano.gov/node/681). These strategic documents guide how NNI agencies address the full range of nanotechnology research and development, technology transfer and product commercialization, infrastructure and education, as well as the societal issues that accompany an emerging technology. The investments in 2011 and 2012 and those proposed for 2013 continue the emphasis on accelerating the transition from basic R&D to innovations that support national priorities such as sustainable energy technologies, manufacturing, and environmental protection. This is reflected in a substantial increase in the nanotechnology investments for 2013 at the Department of Energy and the steady investments at most other participating agencies. The USDA Agricultural Research Service (USDA/ARS) joins the NNI budget crosscut for the first time in 2012, with plans to continue its nanotechnology investment in 2013. DOJ, while still participating in the NNI, is not currently included in the NNI budget crosscut.

The 2013 NNI budget supports nanoscale science, engineering, and technology R&D at 15 agencies. Agencies with the largest investments are:

- DOE (fundamental and applied research providing a basis for new and improved energy technologies)
- NSF (fundamental research and education across all disciplines of science and engineering)
- NIH (nanotechnology-based biomedical research at the intersection of life sciences and the physical sciences)
- 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)

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

Table 2 presents NNI investments in 2011–2013 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 6 provides approximate investments in Nanotechnology Signature Initiatives by the participating agencies from 2011–2013. Table 7 supplies the NNI investments within Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs. (In Tables 2–7, totals may not add, due to rounding.)

Table 2: NNI Budget, by Agency, 2011–2013 (dollars in millions)			
Agency	**2011 Actual**	**2012 Estimate***	**2013 Proposed**
DOE**	346.2	315.4	442.5
NSF	485.1	426.0	434.9
HHS/NIH	408.6	409.6	408.7
DOD	425.3	361.2	289.4
DOC/NIST	95.9	95.4	102.1
NASA	17.0	23.0	22.0
EPA	17.4	17.5	19.3
HHS/FDA	9.9	11.8	11.1
HHS/NIOSH	10.0	10.0	10.0
USDA/NIFA	10.0	10.0	10.0
DHS	9.0	7.0	6.0
USDA/FS	10.0	5.0	5.0
USDA/ARS	0.0	2.0	2.0
DOT/FHWA	1.0	1.0	2.0
CPSC	1.8	2.0	2.0
TOTAL* **	**1847.3**	**1696.9**	**1767.0**

* 2012 levels reflect estimates based on 2012 appropriated levels.

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

*** In Tables 2–7, totals may not add, due to rounding.

Key points about the 2012 and 2013 NNI investments

- While fundamental research (PCA 1) remains the largest single NNI investment category ($498 million in the 2013 budget), the more applied research in nanodevices and systems (PCA 3) and in nanomanufacturing (PCA 5) now total over $500 million combined, as some areas of nanotechnology mature and applications develop.
- The NNI agencies understand the importance of maintaining the NNI research infrastructure at the cutting edge of scientific capability through ongoing upgrades to facilities and instrumentation, including user facilities available to industry and academia. NNI investments in instrumentation research, metrology, and standards (PCA 4) and in major research facilities and instrumentation acquisition (PCA 6) are sustained at about $70 million and $180 million, respectively, during 2011–2013. This sustained investment also reflects the importance of metrology and standards to commercialization of nanotechnology-enabled innovations.
- The NNI continues to maintain a robust and growing investment in environmental, health, and safety (EHS) research related to nanotechnology (PCA 7), with $105 million requested for 2013, an increase of almost 20% over 2011 actual spending. This increase is guided by the revised NNI EHS Research Strategy that was released in October 2011. Cumulatively the NNI agencies have allocated over $650 million to EHS research since 2005, including the 2013 President's Budget Request.

Table 3: Actual 2011 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	101.0	112.1	9.6	10.6	5.0	107.9	0.0	0.0	346.2
NSF	182.1	98.5	55.8	12.9	44.8	35.1	22.4	33.4	485.1
HHS/NIH	74.1	84.2	191.5	22.8	1.3	11.4	20.2	3.1	408.6
DOD	186.0	33.0	161.0	2.0	24.3	18.0	1.0	0.0	425.3
DOC/NIST	21.7	7.3	20.8	16.9	14.6	11.4	3.2	0.0	95.9
NASA	0.0	7.0	9.0	0.0	1.0	0.0	0.0	0.0	17.0
EPA	0.0	0.0	0.0	0.0	0.0	0.0	17.4	0.0	17.4
HHS/FDA	0.0	0.0	0.0	0.0	0.0	0.0	9.9	0.0	9.9
HHS/NIOSH	0.0	0.0	0.0	0.0	0.0	0.0	10.0	0.0	10.0
USDA/NIFA	1.0	2.0	4.0	0.0	0.0	0.0	2.0	1.0	10.0
DHS	0.0	0.0	2.0	7.0	0.0	0.0	0.0	0.0	9.0
USDA/FS	2.0	3.0	1.0	1.0	1.0	2.0	0.0	0.0	10.0
DOT/FHWA	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
CPSC	0.0	0.0	0.0	0.0	0.0	0.0	1.8	0.0	1.8
TOTAL	**567.9**	**348.2**	**454.7**	**73.2**	**92.0**	**185.8**	**88.0**	**37.5**	**1847.3**

Table 4: Estimated 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	103.7	82.4	9.1	14.5	0.0	105.6	0.0	0.0	315.4
NSF	146.3	78.8	52.4	12.1	47.8	28.5	30.0	30.1	426.0
HHS/NIH	74.6	84.0	192.3	22.6	1.3	11.4	20.3	3.1	409.6
DOD	162.0	42.2	126.8	2.0	11.2	15.1	2.0	0.0	361.2
DOC/NIST	21.5	7.3	17.8	16.1	9.2	16.4	7.2	0.0	95.4
NASA	0.0	9.0	11.0	0.0	3.0	0.0	0.0	0.0	23.0
EPA	0.0	0.0	0.0	0.0	0.0	0.0	17.5	0.0	17.5
HHS/FDA	0.0	0.0	0.0	0.0	0.0	0.0	11.8	0.0	11.8
HHS/NIOSH	0.0	0.0	0.0	0.0	0.0	0.0	10.0	0.0	10.0
USDA/NIFA	1.0	2.0	4.0	0.0	0.0	0.0	2.0	1.0	10.0
DHS	0.0	0.0	0.0	7.0	0.0	0.0	0.0	0.0	7.0
USDA/FS	1.0	2.0	0.0	1.0	1.0	0.0	0.0	0.0	5.0
USDA/ARS	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0
DOT/FHWA	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
CPSC	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	2.0
TOTAL	**510.1**	**310.7**	**413.4**	**75.3**	**73.5**	**177.0**	**102.7**	**34.2**	**1696.9**

Table 5: Proposed 2013 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	117.1	146.3	39.7	11.9	9.0	118.5	0.0	0.0	442.5
NSF	146.3	81.3	53.9	12.1	52.8	28.5	29.9	30.1	434.9
HHS/NIH	74.4	83.9	191.9	22.5	1.3	11.4	20.2	3.1	408.7
DOD	138.0	32.7	95.6	1.0	6.2	15.0	1.0	0.0	289.4
DOC/NIST	20.4	7.2	17.8	14.7	15.7	16.4	9.9	0.0	102.1
NASA	0.0	9.0	10.0	0.0	3.0	0.0	0.0	0.0	22.0
EPA	0.0	0.0	0.0	0.0	0.0	0.0	19.3	0.0	19.3
HHS/FDA	0.0	0.0	0.0	0.0	0.0	0.0	11.1	0.0	11.1
HHS/NIOSH	0.0	0.0	0.0	0.0	0.0	0.0	10.0	0.0	10.0
USDA/NIFA	1.0	2.0	4.0	0.0	0.0	0.0	2.0	1.0	10.0
DHS	0.0	0.0	0.0	6.0	0.0	0.0	0.0	0.0	6.0
USDA/FS	1.0	2.0	0.0	1.0	1.0	0.0	0.0	0.0	5.0
USDA/ARS	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0
DOT/FHWA	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0
CPSC	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	2.0
TOTAL	**498.2**	**368.4**	**412.9**	**69.2**	**88.9**	**189.9**	**105.4**	**34.2**	**1767.0**

- Consistent with the President's Strategy for American Innovation and recommendations by the President's Council of Advisors on Science and Technology (PCAST) in its 2010 review of the NNI, the Nanotechnology Signature Initiatives (NSIs) aim to catalyze breakthroughs and harness science and technology to address critical challenges of the 21st century. The President's 2013 Budget includes over $300 million in funding for the three NSIs that were introduced in the 2011 Budget: $112 million for Nanotechnology for Solar Energy Collection and Conversion; $84 million for Sustainable Nanomanufacturing; and $110 million for Nanoelectronics for 2020 and Beyond. This represents a 24% increase in NSI investment compared to 2011 actual spending. (See Table 6 and accompanying text on pages 11–13 for details.)

- The NNI nanomanufacturing investment (PCA 5), including both the nanomanufacturing NSI and the broader NNI nanomanufacturing effort, is synergistic and consistent with the goals of the President's Advanced Manufacturing Partnership (AMP). The percentage of the NNI budget crosscut devoted to nanomanufacturing has been sustained over the last several years.

- In keeping with the PCAST recommendation to maintain or expand the level of basic research funding in nanotechnology, the requested NNI investments in research on fundamental nanoscale processes and phenomena (PCA 1) and on nanomaterials (PCA 2) are sustained in 2013 at approximately $850 million combined.

- The most recent data on funding for nanotechnology through the SBIR and STTR programs shows a continued upward trend, with an increase of 5% from $127 million in 2009 to $133 million in 2010, an overall increase of 37% from 2008. Cumulatively, the NNI agencies have funded over $650 million of nanotechnology-related SBIR and STTR awards since 2004. Continued SBIR and STTR funding is consistent with the Administration's emphasis on innovation, commercialization, and job creation.

- Investments in education and societal dimensions of nanotechnology (PCA 8) have been maintained at approximately $35–40 million per year in recent years. Cumulatively the NNI has devoted over $350 million to education and social dimensions investments since 2005, including the 2013 Request.
- USDA’s Agricultural Research Service is joining the NNI budget crosscut for the first time in the 2012 estimate and the 2013 request. As shown in Tables 4 and 5, this investment is focused on nanomaterials (PCA 2).
- As in previous years, investment estimates reported by some agencies (e.g., DOD, DOE) fluctuate from year to year. This variation is associated with several factors. First, at most NNI agencies nanotechnology is not a single programmed investment but is associated with current research needs and opportunities. Nanotechnology must compete for resources with other technologies that contribute to the agencies' missions. Nanotechnology projects have proven to be highly competitive, and generally, actual investments have exceeded the estimates, although this is not guaranteed. Second, specific nanotechnology projects often have milestones that need to be met for continuation, so estimates cannot firmly include these resources. Third, occasionally a substantial new thrust in nanotechnology will enhance funding in a year without significant future funding (for example, one-time expenses for purchase of instrumentation). Hence budget estimate numbers for those agencies are sometimes substantially lower than subsequently reported actual spending.

Nanotechnology Signature Initiatives

In support of the President’s priorities and innovation strategy, Federal agencies participating in the NNI have identified a number of important technology developments that can be more rapidly advanced through focused and closely coordinated interagency research and development efforts. Each *Nanotechnology Signature Initiative (NSI)* defines a shared vision for accelerating the advancement of a particular area of nanoscale science and technology that addresses the Nation’s most pressing needs, including economic recovery and job growth, national security, and energy production.

Nanoscale science and technology research is a multidisciplinary and enabling endeavor that spans a diverse array of science and engineering fields, making it a subject area that benefits from coordinated planning and collaborative research. By combining the expertise, capabilities, and resources of multiple Federal agencies, the NSIs efficiently and effectively move high-priority areas of nanoscale research towards practical application. The focused outcomes of each signature initiative fall within the four foundational NNI goals and across several PCAs. Each contributing agency is committed to coordinating research to achieve these outcomes in order to avoid duplication of effort and maximize the return on the Nation’s research investments. The NSET Subcommittee, in collaboration with OSTP, has identified three NSI topic areas: solar energy, nanomanufacturing, and nanoelectronics. The subcommittee continues to examine other potential areas of nanoscale science and technology that may benefit from similar close coordination.

Funding for three Nanotechnology Signature Initiatives has increased annually since their inception in 2011, as shown in Table 6.[4]

---

[4] Additional details on the NSIs are provided below and online at nano.gov/initiatives/government/signature.

Table 6: Nanotechnology Signature Initiatives, 2011–2013 (approximate funding, dollars in millions)				
Nanotechnology Signature Initiative	**Participating Agencies**	**2011 Actual**	**2012 Estimated**	**2013 Proposed**
Sustainable Nanomanufacturing	DOD, DOE, IC/DNI, NASA, NIOSH, NIST, NSF, USDA/FS	61	73	84
Solar Energy Collection and Conversion	DOD, DOE, IC/DNI, NASA, NIST, NSF, USDA/NIFA	88	89	112
Nanoelectronics for 2020 and Beyond	DOD, DOE, IC/DNI, NASA, NIST, NSF	97	104	110
TOTAL		**246**	**266**	**306**

Nanotechnology Signature Initiative: Sustainable Nanomanufacturing—Creating the Industries of the Future ("NSI Nanomanufacturing")

In support of the President's Advanced Manufacturing Partnership (AMP), this signature initiative is designed to develop new technologies for the manufacture of advanced materials, devices, and systems based on nanoscale building blocks and components. The goal of this initiative is to accelerate the development of industrial-scale methods for manufacturing functional nanoscale systems. The initiative targets production-worthy scaling of three classes of sustainable materials—high-performance structural carbon-based nanomaterials, optical metamaterials, and cellulosic nanomaterials—that have the potential for significant economic impact in multiple industry sectors.

An essential prerequisite for the development of cost-effective nanomanufacturing is the availability of high-throughput, in-line metrology to enable closed-loop process control and quality assurance. The United States has expertise in roll-to-roll manufacturing, which can be adapted to the types of high-volume fabrication processes envisioned. The formation of consortia with industry, government, and academia devoted to the development of metrology and system-integration methods to enable application of roll-to-roll methods to nanomanufacturing is expected to play an essential role. The systems to be manufactured based on these methods can then be extended to other disruptive technologies that require lightweight, high-strength, sustainable materials, such as solar energy harvesting, flexible electronic systems-on-film, waste-heat management and recovery, and energy storage.

This NSI has two thrust areas:

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

Nanotechnology Signature Initiative: Nanotechnology for Solar Energy Collection and Conversion ("NSI Solar")

Solar energy is a promising alternative energy source that has the potential to reduce American dependence on foreign oil, promote healthy ecosystems, and improve the economy. New technological innovations and fundamental scientific breakthroughs are needed to accelerate the development of solar energy that is economically competitive with conventional fossil fuel technologies. Agencies participating in the NNI have identified a number of physical phenomena where nanotechnology may play a critical role in substantially improving the collection and conversion of solar energy at the nanoscale.

Nanoparticles and nanostructures have been shown to enhance the absorption of light, increase the conversion of light to electricity, and provide better thermal storage and transport. Nanostructured artificial photosynthetic systems mimicking those found in nature will be important for the conversion of solar energy into chemical fuels. Critical to exploiting the benefits of nanotechnology is a deeper theoretical understanding of conversion and storage phenomena at the nanoscale, improvements in the nanoscale characterization of electronic properties, and developments that enable economical nanomanufacturing of robust devices. Achieving product lifetime and reliability of technologies incorporating nanotechnology that meet or exceed the performance of conventional technologies is also critical to the success of this initiative.

This NSI has three thrust areas:

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

Nanotechnology Signature Initiative: Nanoelectronics for 2020 and Beyond ("NSI Nanoelectronics")

The semiconductor industry is a major driver of the modern economy and has accounted for a large proportion of the productivity gains that have characterized the global economy since the 1990s. These gains have been achieved due to continuous miniaturization and other advances in semiconductor design and manufacturing, enabling ever smaller and faster devices. Because the physical length scales of electronic devices are now reaching atomic dimensions, it is widely believed that further progress will be stalled by limits imposed by fundamental physics. This multi-agency NSI 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 nanoelectronics.

Approaches to achieving these outcomes could include different types of logic using cellular automata or quantum entanglement and superposition; 3-D spatial architectures; and information-carrying variables other than electron charge such as photon polarization, electron spin, and position and states of atoms and molecules. Approaches based on nanoscale science, engineering, and technology are the most promising for realizing these radical approaches and are expected to transform the very nature of electronics and the processes by which electronic devices are manufactured. Rapidly reinforcing domestic R&D successes in these arenas could establish a U.S. domestic manufacturing base that will dominate 21st century electronics commerce.

This NSI 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
- Expanding the national nanoelectronics research and manufacturing infrastructure network (university-based infrastructure)

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

The 21st Century Nanotechnology R&D Act 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 funding or programmatic changes for 2012 and 2013.

CPSC: Consumer products within the jurisdiction of the Consumer Product Safety Commission are increasing not only in number but also in complexity. Technological progress in areas such as advanced materials, nanotechnology, and biotechnology has fundamentally changed the raw inputs, assembly, and packaging of consumer products. Because data concerning the impact of these new technologies on public health remains limited, the potential risk to consumer safety is difficult to predict. The CPSC is collaborating with other Federal agencies within the NNI to support the development of exposure and risk assessments of nanomaterials and to allow for database updates to flag reports of incidents that involve nanotechnology and consumer products. The CPSC will need to continue to monitor these products closely in order to detect new safety risks as early as possible. The CPSC joined the NNI budget crosscut in 2011 in support of environment, health, and safety (PCA 7) activities that involve data analysis and technical review related to application of nanotechnology in consumer products. In 2012 and 2013, CPSC staff will continue efforts to address product safety through collaborative efforts with other NNI agencies.

DOD:[5] The Department of Defense does not establish funding targets for nanotechnology. New projects are awarded on a competitive basis; due to the competitive success of nanotechnology projects and proposals, the actual investment often exceeds previous estimates and predictions. Nonetheless, based on the state of nanoscience and nanotechnology R&D, DOD expects that its primary emphasis will remain in fundamental nanoscale phenomena and processes (PCA 1), nanoscale devices and systems (PCA 3), and nanomaterials (PCA 2), with an increasing emphasis on nanomanufacturing (PCA 5). Historically, DOD's Technology Base (Budget Activity 1–3) investment in nanotechnology has been approximately 50% Basic Research, 40% Applied Research, and 10% Advanced Technology Development. The bulk of the SBIR/STTR investment in nanotechnology could be categorized as functionally similar to Applied Research, although with a strong, directly commercializable product or process aspect more analogous to Advanced Technology Development. The current expectation is that these overall percentages will be continued through 2013.

DOD research in nanostructured material synthesis has involved processing <20 nm nanoparticles via radio-frequency, inductively-coupled plasma synthesis followed by spark-plasma and pressure-assisted sintering, electric field-assisted high-pressure sintering for nanomaterial consolidation, and electrophoretic deposition of nanoparticle coatings. Potential applications are transparent materials for radomes, infrared domes, and windows; sensor protection; multispectral windows; and shape-conformal nanostructured armor.

The DOD has increased its focused investment in manufacturing related to nanotechnology through the Multidisciplinary University Research Initiative (MURI) and the Small Business Technology Transfer Program. During the first ten years of the NNI, important advances were made in the fundamental understanding of nanoscale phenomena and processes and in the development of nanoscale structures, devices, and systems. The next ten years of the NNI are becoming a decade of implementation, technology transfer, nanomanufacturing, and commercialization. In response to recent external reviews of the NNI, DOD has

[5] Details for Department of Defense investments are provided per the statutory requirement for DOD reporting on its nanotechnology investments (10 USC §2358).

augmented its nanomanufacturing R&D efforts. In 2011 nine MURI topics in nanomanufacturing were selected, from which 10 awards were made. These grants will continue for at least three years.

DOD nanomanufacturing R&D encompasses a wide range of research programs, from basic and applied science to applications and problem solving. An example of basic research is tailoring the electronic bandgap of graphene using techniques such as catalytic nanolithography, scanning probe and directed e-beam nanolithography, and chemical functionalization. A challenge for single-atom-layer electronics is the need for sub-nanometer patterning capability with atomically sharp edges along specific crystal orientations. To meet this challenge, approaches such as crystallographic etching, helium-ion ultrahigh-resolution patterning, and chemical etching methods are pursued. An opportunity is the creation of a new class of high-mobility electronics by pyrolitic direct-writing of high-density graphene circuits on graphene oxide. Devices from the onset of band modification at ~50 nm down to atomically perfect structures with intrinsic quantum mechanical behavior are possible. This direct-write effort is a subset of the tip-based nanofabrication program, the goal of which is to leverage tip arrays and optical techniques to manufacture structures with nanoscale control and precision. The goal of the maskless nanowriter program is to develop electron-beam lithography tools for affordable production of application-specific integrated circuits and mask sets. A popular basic research topic in nanomanufacturing is precision assembly of nanostructures using DNA templating. For example, DNA-origami-induced carbon nanotube field-effect transistors have been demonstrated.

A major DOD research effort is in large-area processing using massively parallel methods. The resulting high-throughput processing usually translates into cost-effective manufacturing of nanostructures. One method is "maskless" nanoimprinting/nanopatterning of metallic thin films over large areas. The solid-state superionic stamping process achieves this in ambient, dry environments and involves electrochemical imprinting by anodic dissolution at the contact interface. By this means complex nanoscale patterns are possible via computer-aided-design-driven parallel processing. Potential applications are data storage and high-resolution sensing. In order to form nanostructures in three dimensions, parallel direct-write freeform fabrication processes are being developed. It was shown that 3-dimensional nanostructures and nanopatterns can be "grown" in functional material baths by photopolymerization and photoablation using multibeam laser interference patterning. To reduce the feature size to sub-micrometer scale, light superfocusing is needed. This can be achieved by near-field diffractive lens or near-field scanning probes and surface plasmon effects. Optical waveguides, photonic band-gap structures, tip arrays for sensing and detection, and molds for nanoimprinting are some possible applications.

DOD nanomanufacturing research efforts are also directed at system-level integration. For example, in the development of a next-generation fuel cell system, nanoscale processes such as atomic layer deposition, polyol process, and polymer blends are used to optimize component materials for performance and cost. Other components are optimized using macroscale processes such as additive manufacturing. Together, system integration is accomplished for maximum performance, enhanced efficiency, and reduced production cost. System-level integration is also needed to build a full-function hybrid flexible electronic system and requires nanoscale organic and inorganic semiconductor, dielectric, and conductor inks to form a family of devices on flexible substrates designed to perform functions such as a display, sensor, antenna, logic, memory, speaker, and switch, powered by a thin-film battery or solar cell. Besides nanomaterial and nanodevice requirements, there are manufacturing requirements. For the high-speed manufacture of a multifunctional electronic system-on-film, a continuous roll-to-roll platform is needed. Manufacturing challenges are rheology and printing for feature size and resolution; automated in-line registration correction; high-speed integrated optical, electrical, and mechanical quality assurance tooling; in-plane substrate deformation correction; integrated automated metrology tools and defect recognition; and tools for real-time manufacturing metrics. DOD can benefit from flexible communication systems, transparent displays for windshields and helmets, wrist-worn displays, organic light-emitting diodes for illumination, skin patch sensors, head trauma sensors, and flexible photovoltaics.

DOE: There have been no significant changes in the balance of DOE investments among the eight PCAs.

DOT/FHWA: The Federal Highway Administration (FHWA) investment in nanomaterials (PCA 2) will be maintained.

EPA: There are no significant changes in EPA's balance of nanotechnology-related investments in 2012. In 2013, EPA's nanotechnology resources increase by $1.9 million compared to 2011. This increase reflects an intensified focus on providing new principles for innovative chemical designs that are more environmentally sustainable and reduce the likelihood of unwanted toxic effects of nanomaterials.

FDA: FDA investments in environment, health, and safety (PCA 7) will continue to enable the agency to address questions related to the safety, effectiveness, quality, and/or regulatory status of products that contain nanomaterials or otherwise involve the use of nanotechnology; develop models for safety and efficacy assessment; and study the behavior of nanomaterials in biological systems and their effects on human health.

FDA has developed a regulatory science program in nanotechnology to foster the responsible development of FDA-regulated products that may contain nanomaterials or otherwise involve the application of nanotechnology.[6] The FDA program establishes tools, methods, and data to assist in regulatory decision-making while providing in-house scientific expertise and capacity that is responsive to nanotechnology-related FDA-regulated products. This program addresses the following agency-wide priorities: (1) scientific staff development and professional training, (2) laboratory and product testing capacity, and (3) collaborative and interdisciplinary research to address product characterization and safety.

Together, these programmatic investment areas will better enable FDA to address key scientific gaps in knowledge, methods, and tools needed to make regulatory assessments of these products.

IC/DNI: The National Reconnaissance Office (NRO) and the Office of the Secretary of Defense will initiate bulk carbon nanotube (CNT) sheet and yarn production in a new pilot plant in 2012, under Title III of the Defense Production Act. This begins a joint effort on scaling to commercial capacities that is scheduled by 2014. This pilot production facility is the first of its kind in the world.

NASA: Increased investments by NASA in nanomanufacturing (PCA 5) and nanomaterials (PCA 2) in 2012 are due to the initiation of a new project to develop high-strength fibers from carbon nanotubes and incorporate them into fiber-reinforced polymer matrix composites.

NIH: NIH does not anticipate significant changes to its balance of investments in the NNI PCAs.

NIOSH: The National Institute for Occupational Safety and Health tracks and reports its investment in nanotechnology research on environment, health, and safety (PCA 7). NIOSH's research results have application and interface with other PCAs such as nanomanufacturing (PCA 5). As the only U.S. Government agency responsible for conducting research on the occupational safety and health implications and applications of nanotechnology, maintaining the internal funding needed for a viable program remains a priority. For 2013, NIOSH will continue to increase its investment in three key areas of

[6] See FDA's Nanotechnology Regulatory Science Research Plan, www.fda.gov/ScienceResearch/SpecialTopics/Nanotechnology/ucm273325.htm.

emphasis: (1) application of Prevention through Design (PtD) principles to the development of new nanomaterials, tasks, tools, and facilities; (2) developing and disseminating effective containment and control strategies needed to support safe and responsible development of nanomaterial-based products; and (3) building a broad base of knowledge of worker exposure and health experience in key high-volume nanomaterial industries and applications such as carbon nanotubes, titanium dioxide, and nano-silver. Emphasis areas 1 and 2 are in direct support of NSI Nanomanufacturing.

Increasing activity in these emphasis areas will be achieved by internal redirection of existing funds. NIOSH will continue to build partnerships with private sector nanomaterial companies and will coordinate efforts with other NNI agencies, including OSHA, NIST, CPSC, EPA, and DOD. Updates of the NIOSH Nanotechnology Strategic Plan (2013–2015) and the NIOSH Progress Report (2004–2011) reflect the new areas of emphasis and describe ongoing efforts and results from the 2010–2012 plan, which continues NIOSH efforts to understand potential human health effects by exploring biologic mechanisms of nanomaterials and characterize risk by evaluating worker exposures.

NIST: The President's 2013 Budget request for NIST will continue to support research in nanotechnology, including significantly increased investments begun in 2012 in the intramural laboratories and user facilities for nanomanufacturing (PCA 5), major research facilities and instrumentation acquisition (PCA 6), and environment, health, and safety—"nanoEHS" (PCA 7). Compared with 2011 levels, the requests in 2013 will increase the budget for PCA 6 by 44% and triple NIST's investments in PCA 7. The Technology Innovation Program (TIP), which made $6.6 million of extramural investments in nanomanufacturing in 2011, received no funds in 2012, and the program is currently taking the necessary actions for an orderly shutdown. However, the intramural budget for nanomanufacturing will double in 2013 compared with the 2011 level, more than counterbalancing the reduction associated with TIP. Other funding amounts among PCAs have changed slightly because of better classification of current and planned research.

The increased investments in NIST intramural research will accelerate the development of measurements to support the manufacture and production of nanotechnology-based products in support of NSI Nanomanufacturing, including the manufacture of carbon-based nanomaterials and the development of smart manufacturing through advanced nanopositioning robotic metrology, sensing, and control needed to improve nanoscale product quality and yield. To support large-scale production of nanotechnology-based products, new methods will be developed to characterize nanomanufacturing processes, validate process models, and perform cost-effective in-line measurement and process control.

The equipment and instrumentation in NIST's Center for Nanoscale Science and Technology (CNST) user facility will be updated and enhanced so that it can continue to meet the nanoscale measurement and fabrication needs of rapidly growing numbers of industry customers and other stakeholders.

NIST's expanded nanoEHS program is supporting the safe manufacture, use, and disposal of engineered nanomaterials (ENMs) and nanotechnology-enabled products. NIST will develop measurement methods and standards, based on advances in underlying measurement science, to detect and characterize ENMs in nanotechnology-enabled products, sample air containing airborne ENMs, characterize airborne ENMs, and assess the release of ENMs from such products. Ongoing work on developing standard reference materials, measurement protocols, and predictive models will be accelerated. NIST will focus on ENMs of greatest regulatory concern based on production volume, widespread use in products, and potential hazards—namely, silver, titanium dioxide, cerium oxide, carbon nanotubes, and clay-based composites containing these ENMs. NIST will coordinate with manufacturers of ENMs and ENM-based products; other NNI agencies, particularly NIOSH, OSHA, CPSC, and EPA; and major nanoEHS university centers.

NSF: Six Nanoscale Science and Engineering Centers (NSECs) with an annual budget of about $14 million have graduated in 2011, and 13 NSECs continue their funding through 2013. Three Nanosystems Engineering Research Centers (NERCs) with a total budget of about $10 million will be established in the summer of 2012 and start to fully operate in 2013. Partnerships between new NERCs and small businesses in the areas of nanomanufacturing (PCA 5) and commercialization will be strengthened while maintaining about the same level of NSF investment.

The 2012 NSF investment in nanomanufacturing is estimated at $47.8 million, compared to $44.8 million in 2011. A program solicitation for nanoscale interdisciplinary research teams (NIRTs) was completed in 2011 and another is being considered for this purpose in 2012. Partnerships with NIST, DOD, and other NNI agencies are planned.

With $52.8 million in 2013 funding for nanomanufacturing, NSF will increase support for single-investigator and interdisciplinary research teams by approximately $8 million compared to 2011 in the following areas: (a) novel processes and techniques for continuous and scalable nanomanufacturing; (b) directed (physical/chemical/biological) self-assembly processes leading to heterogeneous nanostructures with the potential for high-rate production; (c) principles and design methods to produce machines and processes to manufacture nanoscale structures, devices, and systems; and (d) long-term societal and educational implications of the large-scale production and use of nanomaterials, devices, and systems, including life-cycle analysis.

The NSF investment in solar energy for single investigators and interdisciplinary research teams is estimated to remain at $32 million and covers the following areas: (a) improving efficiency of photovoltaic solar electricity generation with nanotechnology; (b) developing thermoelectric converters for solar thermal energy generation and conversion with nanotechnology; and (c) improving solar-to-fuel conversions with nanotechnology. NSF will collaborate with DOE and other NNI agencies.

About $45 million is included in the 2013 NSF budget in support of NSI Nanoelectronics, compared to $38 million in 2011. This request will fund grants to advance the forefront of computation, information processing, sensor technologies, and communications infrastructure beyond the physical and conceptual limitations of current technologies. The initiative is intended to support proposals by single investigators and interdisciplinary teams of investigators committed to exploring innovative research concepts in nanoelectronics involving fundamental challenges in areas ranging from novel materials, chemistry, and logic devices, to circuit designs and systems architectures, algorithms, and perhaps entirely new paradigms of computation, sensing, and processing of information. The following themes will receive priority: (a) new chemistries and materials for nanoelectronics; (b) alternative state variables and heterogeneous integration for nanoelectronic devices and systems, and (c) novel paradigms of computing. Co-funding with the Semiconductor Research Corporation and other NNI agencies is planned.

USDA/FS: In 2012, Forest Service nanotechnology research will place greater emphasis on renewable nanocellulose materials from the forest. Forest Service nanotechnology research investments will be allocated to 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). The Forest Service is considering long-term plans to broaden its nanotechnology research investments to include environmental, health, and safety issues and societal implications of nanotechnology in renewable materials (PCAs 7 and 8).

USDA/NIFA: The National Institute of Food and Agriculture will maintain a balanced portfolio across the PCAs similar to previous years. The primary emphases are in PCAs 1, 2, 3, 7, and 8. The Agriculture and Food

Research Initiative (AFRI) Competitive Grants Program on Nanotechnology for Agricultural and Food Systems continues to support nanotechnology innovations that address a broad range of critical challenges and opportunities facing agriculture and food systems. Relative to PCA 7, AFRI's Physical and Molecular Mechanisms of Food Contamination program has added a new priority in 2011 of elucidation of mechanisms that allow unintended engineered nanoparticles to attach onto and internalize into fresh food crops, including nuts, and development of detection methods to evaluate exposure to unintended engineered nanoparticles in fresh food.

USGS: The U.S. Geological Survey has several projects that focus on nanoparticles, with a primary focus in environment, health, and safety (PCA 7) to support responsible development of nanotechnology.

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, EPA, NIOSH, NIST, and USDA have SBIR programs. Table 7 shows agency funding for SBIR and STTR awards for nanotechnology R&D from 2006 through 2010 (the latest year for which data are available).

Some NNI agencies (e.g., NIH and NSF) have nanotechnology-specific topics in their planned SBIR and STTR solicitations. The NSF SBIR program has an ongoing nanotechnology topic with subtopics for nanomaterials, nanomanufacturing, nanoelectronics and active nanostructures, nanotechnology for biological and medical applications, and instrumentation for nanotechnology. Some agencies have had additional topical or applications-oriented solicitations for which many awardees have proposed nanotechnology-based innovations. SBIR/STTR data for 2004–2010 indicates that the NNI agencies have funded over $650 million of nanotechnology-related SBIR and STTR awards. Note that a significant portion of SBIR/STTR funding reported by DOE for 2009 and 2010 is from the American Recovery and Reinvestment Act (ARRA) of 2009. Data for 2006–2010 are shown in Table 7, and a complete listing by year (including data from 2004 and 2005) can be found at nanodashboard.nano.gov.

Table 7: 2006–2010 Agency SBIR and STTR Awards
(dollars in millions)

	2006			2007			2008			2009			2010		
	SBIR	**STTR**	**Total**	**SBIR**	**STTR**	**Total**	**SBIR**	**STTR**	**Total**	**SBIR**	**STTR**	**Total**	**SBIR**	**STTR**	**Total**
DOD	12.6	5.6	18.2	8.4	4.2	12.6	19.8	2.3	22.1	19.3	3.9	23.2	32.2	10.4	42.6
NSF	13.9	1.8	15.7	13.4	3.8	17.2	10.5	7.5	18.0	13.2	7.0	20.2	25.2	3.9	29.2
NIH	15.1	2.1	17.2	18.4	1.1	19.5	29.3	1.8	31.1	23.0	3.7	26.7	21.7	1.6	23.2
NIOSH	0.1	0.0	0.1	0.1	0.0	0.1	0.4	0.0	0.4	0.7	0.0	0.7	0.0	0.0	0.0
DOE	18.2	1.6	19.8	17.4	0.8	18.2	13.8	2.7	16.5	31.9	5.7	37.6	19.4	4.4	23.8
NASA	12.1	1.5	13.6	11.7	1.5	13.2	6.2	0.8	7.0	15.0	1.7	16.7	11.6	2.1	13.7
EPA	1.2	0.0	1.2	0.5	0.0	0.5	0.7	0.0	0.7	0.7	0.0	0.7	0.4	0.0	0.4
USDA	0.7	0.0	0.7	1.1	0.0	1.1	0.9	0.0	0.9	0.5	0.0	0.5	0.0	0.0	0.0
NIST	0.1	0.0	0.1	0.3	0.0	0.3	0.4	0.0	0.4	0.4	0.0	0.4	0.2	0.0	0.2
TOTAL	**74.0**	**12.6**	**86.6**	**71.3**	**11.4**	**82.7**	**81.9**	**15.1**	**97.0**	**104.6**	**22.0**	**126.6**	**110.6**	**22.4**	**133.0**

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, this NNI Supplement to the President's Budget provides an analysis of the progress made toward achieving the goals and priorities established for the National Nanotechnology Initiative. The NNI's activities for 2011 and 2012 and plans for 2013 are reported here in terms of how they promote progress toward the four NNI goals set out in that plan. It is important to note that many agency programs and activities, although listed below under their primary NNI goals, address components of multiple goals simultaneously. Therefore an integrated perspective across the four goals is needed to understand progress towards achieving the NNI vision.

Goal-related activities are reported below in terms of two categories of activities: (1) individual agency activities and (2) coordinated activities of NNI agencies with other agencies and with groups external to the NNI, including international activities. *The activities described below in terms of these two categories 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

This NNI goal seeks to expand the boundaries of scientific knowledge and to develop practical new technologies through comprehensive and focused nanotechnology research and development at the frontiers and intersections of scientific disciplines. The member agencies have sustained a strategic investment in fundamental nanotechnology R&D, an essential component 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.

The 2011 NNI Strategic Plan defines Goal 1 objectives[7] as (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. The objectives include development of better metrics to assess the NNI R&D programs in terms of innovation and comparison to other countries' R&D programs. Examples of efforts toward all four components of this goal are presented below.

Individual Agency Contributions to Goal 1

DOD: The broad focus and content of the Department of Defense nanotechnology efforts are associated largely with this goal. Nanoscience and processing of materials at the nanoscale are important aspects for increasing the specific performance of materials and are items upon which future defense capability can be

[7] For the full descriptions of the objectives of this NNI goal, see the 2011 *National Nanotechnology Initiative Strategic Plan*, http://nano.gov/node/581 or nano.gov/about-nni/what/vision-goals.

built. DOD nanotechnology research spans the fundamental to applied research spectrum and includes a strong applications emphasis. Examples of R&D projects and progress follow.

- Work funded by DOD and related work within the Air Force have allowed University of California at Los Angeles researchers to report recently on the formation, structural analyses, and optical properties of GaInP/GaP self-catalyzed core–shell double heterostructure nanowires grown on silicon (Si[111]) substrates. The nanowire growth is initiated with the formation of Ga droplets as catalysts, followed by the growth of GaP core and GaInP double heterostructure shells. Structural analysis elucidates the existence of interfaces among GaP core and GaInP double heterostructure shells. Light emissions at 640 and 800 nm are observed at 77 K from GaInP core–shell double heterostructure nanowires and surface states of GaInP layers, respectively. The signal from the surface state can be mitigated via surface passivation with ammonium sulfide solution. These results will enable the realization of novel nanowire-based light-emitting diodes or nanolasers grown on Si substrates utilizing mature silicon microdevice technologies.
- DOD-funded researchers at the University of California at Los Angeles are developing nanohybrid composite scintillators that could replace plastic scintillators currently used for the detection of radiological and nuclear material. These nanohybrid composite scintillators could be low-cost and allow for fabrication of a variety of sizes of detectors. The light yield measured from some small samples of these nanohybrid composites was as high as ~26,000 photons per MeV, which is two times higher than some of the best light yield values obtained from commercial plastic scintillators. Early radiation testing of these nanohybrid composites demonstrated a photoelectric peak for a Cs-137 source with an energy resolution of ~10% at 662 keV.
- Nanotechnology offers unique capabilities for the development of novel advanced materials that can be employed as active or passive sensors for assuring tamper-proof compliance with treaties. Research sponsored by the Defense Threat Reduction Agency at Arizona State University is doing basic research to investigate the potential for nanoparticle-polypeptide matrices to be employed in unattended sensing, based on phase transitions in the polypeptide brought about by nanoparticle response to radiation. Previous studies investigated heat transfer from near-infrared absorbing gold nanorods that results in a conformational change in self-assembled elastin-like polypeptides, leading to a detectable optical response within minutes. Gold nanorods have been studied for use in diagnostics or therapeutics. Future research will explore multiple indicators for radiation or presence of sulfur-containing compounds.
- The monolayer carbon material called "graphene" has come to be of great interest, as evidenced by the 2010 Physics Nobel Prize in this area. It has a range of exceptional properties, including the highest known carrier mobility, highest strength, and highest thermal conductivity. Thus, it holds promise to open important opportunities in electronics, sensing, and strong materials if some of its properties, such as electrical band gap and chemical reactivity, can be modified. Researchers in the Naval Research Laboratory (NRL) Nanoscience Institute have discovered and demonstrated a method to modify its properties by bonding fluorine atoms to its surface. The resulting monolayer system is a Teflon-like material (also a fluorocarbon) that exhibits a range of widely controllable properties, including variations in optical transparency, large electrical band gaps, highly insulating phases, and greatly increased chemical reactivity, all of great interest in a range of technologies from tribology to electronics.
- The development of quantum computing in practical semiconductor material systems would open opportunities for revolutionary advances in ultrasecure communications and real-time processing of very large data arrays, applications of great importance to the Navy. Scientists at the NRL Nanoscience Institute have been at the forefront of developing a physical realization for quantum information using semiconductor quantum dots. Recently, NRL has demonstrated control of the quantum entanglement between two quantum dots using ultrafast laser pulses. This was accomplished by first fabricating pairs

of quantum dots separated by nanometer-thick barriers, and then developing special patterns of picosecond laser pulses to control the relative quantum states of the two dots.

- Combining biologicals such as proteins, peptides, and DNA with nanoparticles derived from gold or semiconductors can allow the generation of hybrid materials that exploit the unique properties of each component to create new functional nanoscale devices with applications ranging from light-harvesting to biosensing and nanomedicine. These composite materials represent the main focus of the rapidly growing field of bionanotechnology. Research towards these goals has, however, been significantly hampered by the lack of available bioconjugation chemistries that can allow the design and controlled formation of such materials as needed. Researchers sponsored by NRL's Nanoscience Institute have directly addressed this crucial technology gap by creating a family of chemistries that allow for controlled placement of biomolecules on nanoparticle materials. The utility of these chemistries has been functionally highlighted by the creation of numerous nanoparticle-based sensors for ions, enzyme activity, and toxins, and have even included a nanoparticle fluorescent protein sensor configuration capable of assembling itself *inside* a living cell. More importantly, the contribution of these bioconjugation chemistries is demonstrated in their growing adoption by other researchers both in the United States and around the world.

- Researchers supported by the Office of Naval Research at the University of California Riverside, Penn State University, and Columbia University, all independently and using complementary techniques, have observed electronic bandgap in trilayer graphene that depends sensitively on the stacking order of the individual graphene layers. Monolayer bulk graphene is a semimetal and has zero bandgap, and bilayer graphene has a voltage-tunable bandgap—discovered last year by researchers at the University of California Berkeley. Electronic bandgap is considered essential for graphene-based transistors for digital logic circuits.

- The DOD endorses coordination and collaboration very broadly in its nanoscience and technology efforts. Within the DOD, the Army and Air Force are coordinating research on nanoinformatics and prediction of nanomaterials attributes. This research has focused on the analysis of human and ecological risks for military-relevant nanoparticles through internal cooperation and collaboration to advance NNI goals. The Army Aviation and Missile Research Development and Engineering Center (AMRDEC) has been conducting efforts to coordinate with the Edgewood Chemical Biological Center (ECBC) for testing and validating AMRDEC-developed chemical/gas nanosensors. AMRDEC is currently collaborating with the Defense Advanced Research Projects Agency (DARPA) to develop nanotechnology-enhanced sensors for toxic industrial chemicals associated with a DARPA-funded effort. AMRDEC is also collaborating and leveraging multiple nanotechnology programs with the Army Research Laboratory (ARL) to broaden subject matter expertise and utilize specialized laboratories and equipment.

DOE: The focus and content of the DOE nanotechnology efforts are broadly associated with NNI Goal 1. The DOE Office of Science supports a broad and diverse investment in nanoscience research and development, primarily through grants to individual researchers at universities, funding for research groups at DOE laboratories, support of interdisciplinary efforts such as the Energy Frontier Research Centers, and operation of five Nanoscale Science Research Centers (NSRCs), which are user facilities for advancing nanoscale science and engineering research. In addition, 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. JCAP continues to receive sustained funding, and it is estimated that approximately 20% of its activities involve nanotechnology. A similar Energy Innovation Hub focused on batteries and energy storage will be initiated in 2012, and it is anticipated that a significant fraction of that effort may also involve nanotechnology. By fostering unique, 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.

The DOE Office of Energy Efficiency and Renewable Energy (EERE) also has significant nanotechnology investments, particularly in the Solar Energy Technologies Program. Nanoscience and processing of materials at the nanoscale are important aspects for increasing the specific performance of materials that relate to solar energy conversion. For example, progress has been made in research in advanced light trapping at the nanoscale to enhance solar cell efficiency. Creation of nanoscale features in silicon using catalytic etching of metals by nanoparticles has enabled the demonstration of a new world record for energy conversion efficiency (18.2%) by black silicon solar cells. This invention earned the research team at the National Renewable Energy Lab an R&D 100 award.

DOT/FHWA: FHWA is investigating nanoscale approaches for monitoring and mitigating degradation of structural materials. In 2012, FHWA-funded research continues to examine nanoscale additives to improve interface behavior in cementitious materials. These efforts, combined with better multiscale modeling capabilities to predict material response under complex loads, aim to significantly improve the durability and performance of transportation infrastructure.

IC/DNI: The National Reconnaissance Office continues work to enhance the properties of carbon nanotubes, specifically in three critical areas: (1) growth of longer CNTs with a goal of 7 mm, (2) better alignment of the CNTs during growth, and (3) increased density of CNTs in sheets and yarns. The net result will be superior composite materials with improved strength and electrical and thermal conductivity. Further research into decreasing direct current (DC) resistivity by 25 times for 48-volt DC data center operations is progressing; the goal is to save 10–15% in power consumption. The challenge to find a resin for CNT composites for superior strength and enhanced acoustic dampening has been initiated under contracts to academia. Researchers have demonstrated the world's first CNT honeycomb core structural material for spacecraft and aircraft use.

NASA: NASA research in nanotechnology is focused on the development of advanced materials, propulsion technology, sensors and electronics, and energy generation and storage systems to meet future mission needs. Current nanotechnology R&D efforts are supported primarily by the Aeronautics and Science Mission Directorates and the Office of the Chief Technologist. These efforts comprise work at eight NASA centers, universities (including University Research Centers at minority-serving institutions), and industry.

A 20+ year roadmap for nanotechnology, one of 14 Space Technology Roadmaps developed under the Office of the Chief Technologist in 2010, has been under review by a National Research Council study panel in a process similar to that used with NASA's Science Mission Decadal Surveys. A report will be delivered to NASA in February 2012 that identifies technology gaps within the roadmaps and recommends funding priorities both within a given roadmap and across all 14 roadmaps. Roadmaps will be revised based upon this feedback and updated annually to reflect changes in funding and new technology breakthroughs. NASA will use these roadmaps as guidelines for future R&D funding priorities.

NIH: The National Institutes of Health advance world-class nanotechnology R&D through multiple pathways, including solicited and unsolicited research program grants. As a result of these programs, the NIH funds multiple meritorious nanotechnology projects through an omnibus R01 and R21 solicitation as well as nanotechnology-specific initiatives. Currently, there are four funding opportunity announcements that target nanotechnology R&D: (1) PA-11-148: a trans-NIH R01 initiative to advance "Nanoscience and Nanotechnology in Biology and Medicine"; (2) PA-11-149: a trans-NIH R21 initiative to advance "Nanoscience and Nanotechnology in Biology and Medicine"; (3) PA-10-149, "Bioengineering Nanotechnology Initiative" (STTR [R41/R42]); and (4) PA-10-150 "Bioengineering Nanotechnology Initiative" (SBIR [R43/R44]).

Specific examples of NIH investigator-initiated research projects include the design of multifunctional and multi-analyte diagnostic systems that define early-stage changes or progression to a disease state, new nanometer-size building blocks for dental restoratives, and nanotherapeutics to treat cancer and other diseases. Other opportunities using nanoscale probes and other nanotechnology-based imaging technologies are being developed to examine, for example, inflammation, metastasis, and angiogenesis. Nanoscale multifunctional materials allow significant progress to be made in targeted delivery of molecular therapies with enhanced efficacy.

Major NIH Programs

Although the majority of NIH funding in nanotechnology is awarded using investigator-initiated grant mechanisms, three major NIH programs complement those efforts: (1) the NCI Alliance for Nanotechnology in Cancer, (2) the NHLBI Programs of Excellence in Nanotechnology, and (3) the NIH-wide Nanomedicine Development Centers.

In September 2010, the *Alliance for Nanotechnology in Cancer* of the National Cancer Institute (NCI) funded a variety of programs 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 postdoctoral scientists working on cancer nanotechnology from mentored environments to independence. During the past year, alliance researchers sponsored by NCI have made significant advances in the development of promising nanotechnology-enabled treatments and diagnostics. Several specific examples follow of NCI's investments related to Goal 1:

- A fast, portable, and potentially inexpensive method of detecting cancer from human biopsy samples by using a handheld molecular imaging device in combination with magnetic nanoparticles and a smartphone. This device is superior to traditional three-day histopathology methods in terms of both diagnostic accuracy and speed.
- Microfluidic devices for rapid diagnosis and monitoring of effectiveness of therapies of multiple cancers using sensitive detection of protein panels. This technique is very fast (capable of reporting the outcome in 10–15 minutes), inexpensive, and portable.
- A strategy that uses nanoparticles to treat tumors with a mélange of anticancer agents. This strategy relies on using silica nanoparticles honeycombed with cavities that can store large amounts and varieties of drugs loaded inside a lipid-based nanoparticle known as a liposome. Researchers have also developed a parallel nanoscale platform using virus-like particles of bacteriophage MS2 that are capable of encapsulating large amounts of cargo in their interiors.
- Several other strategies involving delivery of toxic chemotherapies (and making them less toxic and more effective) and using different types of nanoparticles—polymeric, silica, and others—to treat pancreatic, ovarian, brain, breast, prostate, and lung cancers.
- Particle-based delivery of novel genetic therapies using small-interfering RNA (siRNA).
- An implantable device that is capable of monitoring the level of a cancer biomarker for a month using a conventional MRI scanner. Such measurements could provide early clues of metastasis and evidence that a drug is having the desired effect on a tumor.

The National Heart, Lung, and Blood Institute (NHLBI) *Programs of Excellence in Nanotechnology* (PENs) continue to perform basic and translational research aimed at improving diagnosis and treatment of heart, lung, and blood diseases. Progress has been made in the targeted delivery of therapeutics for prevention of arterial restenosis and for down-regulation of inflammatory monocytes by delivery of siRNA. Diagnostics represents another area where rapid progress is being made, including the development of magnetic resonance biosensors for point-of-care diagnostics.

NIH also continues to support its Common Fund Program on Nanomedicine. All NIH institutes and centers participate in supporting a network of *Nanomedicine Development Centers* that represent a unique approach to translational biomedical research. The centers were challenged to develop a deep understanding of a fundamental biological system and gradually move the research to apply this basic knowledge to improve understanding, diagnosis, and treatment of one or more diseases. This requires a multidisciplinary effort in which teams of scientists and clinicians are working together to improve health. In 2011, Phase II of the nanomedicine program was funded to apply fundamental knowledge and tools to understand and treat specific diseases. The Nanomedicine Development Centers will continue to expand knowledge of the basic science of nanostructures in living cells, will gain the capability to engineer biological nanostructures, and then will apply the knowledge, tools, and devices to focus on specific target diseases. The bold, exciting challenges of this program represent a unique approach to combining nanoscale science—understanding and manipulating cellular nanostructures—with specific medical therapies.

NIST: The nanotechnology R&D program at the National Institute of Standards and Technology 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 nanowire-based test structures to advance nonvolatile memory technologies; improving fabrication processes for silicon-based molecular electronic devices; creating methods to fabricate and test nonvolatile computer memory devices; elucidating key properties of graphene and graphene-based devices; finding new methods to understand spin transport, dynamics, and related magnetic interactions in electronic and data storage devices; and developing innovative ways to measure and manipulate photons in nanophotonic applications.
- NIST is developing quantitative atom probe and advanced electron microscopy instruments based on measurement science advances to enable broader application of these instruments in technologies ranging from semiconductor and data storage to biotechnology and optoelectronics. New methods and instrumentation are under development to accurately measure nanomechanical properties traceable to SI (International System of units) base units, including intrinsic standards based on atomic and single-molecule forces. NIST is developing test methods and reference materials for characterizing scanning probe instruments used in nanomanufacturing processes and metrology, and for identifying defects in nanoelectromechanical systems at the wafer level. NIST researchers are also developing novel techniques for nanoparticle metrology, such as a technology for on-chip size separation and measurement of nanoparticles, and methods for determining and tracking the motion of single nanoparticles.

NSF: NSF provides continued strong support of the NNI through core programs and NNI-solicited awards in NSECs, the National Nanotechnology Infrastructure Network (NNIN), the Network for Computational Nanotechnology (NCN), the Nanoscale Informal Science Education Network (NISE Net), and other programs. NSF's investments for Goal 1 include support for 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 the atomic and molecular levels for about 5,000 active NSF awards. Research areas include discovery and understanding of novel phenomena, quantum control, self-assembly, and basic engineering processes at the nanoscale, as well as understanding complex and emerging behavior of nanosystems, and creating nanomaterials and nanosystems by design.

The 2013 budget includes support from across NSF for 13 NSECs. In 2011 NSF provided $38 million for research in support of NSI Nanoelectronics, including $18 million for a dedicated solicitation in collaboration with the Semiconductor Research Corporation (SRC). NSF directorates participating in the solicitation included Computer and Information Science and Engineering (CISE), Engineering, and Math and Physical Sciences (MPS). In 2012 NSF is providing $9.75 million to transition 4 graduating NSECs and fund three new NERCs. The Network for Computation Nanotechnology (NCN) is being recompeted in 2012.

In 2012–2013 NSF will also support advancement of the NNI through complementary contributions by its various directorates to the Materials Genome Initiative and the Sustainable Energy Pathways Initiative. The NSF Division of Chemistry is planning a workshop on nanoelectronics for 2012.

Examples of projects funded by NSF in support of Goal 1 include the following:

- *Size Matters: Smaller Particles Could Make Solar Panels More Efficient.* Studies done by researchers at the Colorado School of Mines could significantly improve the efficiency of solar cells. For this study, the researchers used an NSF-supported high-performance computer cluster to quantify the relationship between efficiency and particle size in the solar cell. According to them, "We can now design nanostructured materials that generate more than one exciton from a single photon of light, putting to good use a large portion of the energy that would otherwise just heat up solar cells."
- *Computational Discovery of Boron Nitride Nanotubes as Water Channels.* Development of biology-inspired devices is of critical importance towards developing next-generation sensors, computing elements, drug discovery, bio-batteries, and many other applications. Because of their superior electrical, mechanical, thermal, and chemical properties, carbon nanotubes are being investigated to create biomimetic sensors and water channels. Using advanced computational tools, researchers at the University of Illinois have shown that the water transport properties of boron nitride nanotubes can be superior to those of carbon nanotubes. These results take us one step closer towards realizing synthetic versions of aquaporin water channels. Even though boron nitride nanotubes had been shown earlier to possess many excellent physical properties, including thermal and mechanical properties, their water transport properties were previously unknown.

USDA/ARS: ARS nanotechnology investments include research in the following areas:

- Processing technologies to produce healthy, value-added foods from specialty crops (including applications of methylcellulose and chitosan nanoparticles in edible films)
- Imaging technology for food safety and security (including use of Raman scattering with silver nanorods or use of nanoscale peptides and DNA aptamers to detect food-borne pathogens and toxins)
- Novel methods for manufacturing of bioproducts from agricultural feedstocks (including blow spinning and electro spinning biopolymers to produce nanocomposites, nanofoams, nanofibers, microemulsions, and hydrogels)
- Environmentally friendly processes and new applications for animal hides and leather (including collagen-based nanofibers for high-efficiency, biodegradable air filters)

- Development of new bioactive and bio-based products from plant cell wall polysaccharides in sugar beet pulp, citrus peel, and other processing residues (including polysaccharide-based nanoparticles for controlled-release of bioactive food ingredients and for active packaging applications)

USDA/NIFA: NIFA nanotechnology efforts aim to advance nanoscale science, engineering, and technology R&D to address a broad range of grand societal challenges and opportunities facing agriculture and food systems. NIFA is the principal extramural research agency of USDA. Its nanotechnology program 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; improvement of the nutritional quality of foods; early detection and effective intervention technologies for ensuring food safety and biosecurity; and development of new 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 and rapid 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. In addition, NIFA nanotechnology programs also contribute to better understanding of relevant EHS issues.

USPTO: The United States Patent and Trade Office 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 in Section 2 of this report) are being conducted, and cooperation with industry is anticipated.

DOD, universities: As indicated in the DOD section on Individual Agency Contributions to Goal 1, many DOD R&D activities contributing to Goal 1 are performed in conjunction with various U.S. universities.

DOE, DOS, international researchers: DOE's Solar Energy Technologies Program collaborates with the Australian Solar Institute to sponsor several nanotechnology projects as part of the U.S.–Australia Solar Research Collaboration announced by Secretary of State Clinton and Prime Minister Gillard. In addition, DOE's Office of Science and its Solar Energy Technologies Program, in conjunction with India's Ministry of Science and Technology, are jointly funding a U.S.–India Joint Clean Energy Research and Development Center focused on advanced solar research as part of the Partnership to Advance Clean Energy announced by President Obama and Prime Minister Singh. (These activities also support Goal 3.)

DOE, NSF: DOE collaborates in both funding and conducting research with other Federal agencies, as well as international organizations, by issuing joint grant solicitations. For example, NSF and DOE collaborated in a joint Funding Opportunity Announcement in 2011 for the "Foundational Program to Advance Cell Efficiency" in connection with DOE's SunShot Initiative and in support of NSI Solar. As a result of these collaborations, in 2011 DOE's Solar Energy Technologies Program and NSF jointly issued 23 awards in the areas of Transformational Photovoltaic Science and Technology and jointly funded an NSF/DOE Engineering Research Center focused on Quantum Energy and Sustainable Solar Technology.

DOJ, universities, industry: The National Institute of Justice (NIJ) of the U.S. Department of Justice has a communications technology research portfolio that includes research with a focus on advanced multiband antenna technology enabled by radio frequency microelectromechanical systems (RF-MEMS). Researchers at Utah State University (USU) won competitively awarded research grants to investigate the use of RF-MEMS technology as an enabler for a multiband antenna intended to facilitate interoperability and wireless link efficiency for criminal justice and public-safety wireless voice and data applications. L-3 Services Inc., under a separate competitively awarded research grant, is actively working to create an integrated technology research and demonstration platform. This platform will encompass the output and functionality of multiple NIJ-funded research efforts, to include capabilities like those made possible via the USU RF-MEMS antenna research.

NASA, DOD, IC/DNI, universities, industry: In October 2011 NASA co-sponsored a Carbon Nanotubes for Space Applications Technical Interchange Workshop with DOD and NRO. The purpose of the workshop, attended by 160 scientists, engineers, and program managers from the Federal Government, industry, and academia, was to identify the technical barriers to the successful use of carbon nanotubes in structural materials, sensors, and energy generation and storage systems, and to discuss recent research focused on addressing these barriers. NASA will co-sponsor a second workshop in the spring of 2012 focused on the technical challenges to developing high-strength fibers from carbon nanotubes and on identifying approaches to meeting these challenges.

NASA is working with DOD and NRO to develop a series of roadmaps and coordination plans for carbon-nanotube-based structural materials, sensors, electronics, and energy generation and storage.

A new project is being initiated in 2012 to utilize high-strength carbon nanotube fibers and carbon nanoelectronics-based structural health sensors to develop durable, multifunctional structural materials that are 20–40% lighter than conventional aerospace composites. This project is a collaboration between five NASA centers, universities, and industry and will involve partnerships with other Federal agencies under NSI Nanomanufacturing. Materials developed under this effort could find applications in launch vehicle structures, habitats, satellite trusses, cryogenic propellant tanks, airframes, and aircraft engine components.

NIH/NIDCR, NIST: In 2011, NIH's National Institute of Dental and Craniofacial Research (NIDCR) participated in an interagency agreement with NIST to develop clinical standards for resin composite-based dental restorative materials. These restorative materials contain bio-inert nanoparticles with enhanced mechanical properties and/or bioactive nanoparticles having potential antimicrobial properties. The contribution of NIDCR to this effort has been in providing funding support and offering expert basic science and clinical advice to NIST. The focus of NIST in this effort is to design new analytical instrumentation, derivation of standard reference materials, and the modification of existing materials by adding nanoparticle components to endow the materials with antimicrobial properties. Additionally, NIST is developing methods to characterize the properties of the restorative materials at the nanometer length scale. Examples include the development of a surface-enhanced Raman spectroscopy substrate for biofilm quantification using controlled nanotopography and new approaches to quantify demineralization with nanometer resolution using innovative data analysis procedures. The NIDCR's 2012 contribution to this program is currently being assessed.

NIH, USDA/NIFA: NIH and USDA/NIFA co-sponsored a joint workshop, "Using Nanotechnology to Improve Nutrition through Enhanced Bioavailability and Efficacy," 29–30 November 2011 in Bethesda, MD. The goals of the workshop were to evaluate the state of the science and to identify knowledge gaps in the use of nanotechnology to deliver nutrients and bioactive food components for disease prevention; to identify opportunities to improve safe, targeted delivery and controlled release of these components to improve absorption, distribution, metabolism, and elimination; and to catalyze collaborations and stimulate ideas for diet and disease prevention research.

NIST, DOE, industry: Working with SBIR-supported companies, NIST and DOE are jointly developing instruments and methods using synchrotron spectroscopy to characterize the surface chemistry of ENMs with nanometer-scale depth resolution.

NIST, DOD, industry, universities: NIST, DARPA, and industrial and university partners are developing innovative multitip-based nanomanufacturing methods to create nanostructured measurement standards based on the silicon atomic crystal lattice and to serve as development platforms for practical methods for atomic-scale device fabrication.

NSF, NIST, nanoelectronics industry: NSF and NIST continue joint partnerships with the Semiconductor Industry Association (SIA) and the Semiconductor Research Corporation in support of the Nanoelectronics Research Initiative (NRI). The Government's investments in this area (see above under Individual Agency Contributions to Goal 1) were leveraged in 2011 by $20 million in funding from SIA/SRC.

USDA/FS, industry, universities: The USDA Forest Service is working in partnership with the Forest Products Industry's Agenda 2020 Technology Alliance (A2020) and universities to advance 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. The universities are Georgia Institute of Technology, North Carolina State University, Oregon State University, Penn State University, Purdue University, University of Maine–Orono, and University of Tennessee–Knoxville. Establishing an industry-government-university informal partnership provides a way to synergistically combine the marketing and focused-reduction-to-practice skills inherent in industry with the public-interest-based, national-problem-solving capacities of government, and the world-class research capabilities of universities.

Ten new high-priority research projects were initiated in 2011 involving the preceding group of partners. The universities benefit from additional funding for research on projects that provide a direct connection for their work to industry. Industry benefits from access to university and USDA/FS staff and student expertise, from application of nanoscale science and engineering instrumentation/ infrastructure to solve problems of commercial importance, and from access to students who could become employees. The USDA/FS benefits from the cost-sharing contributions of the other partners, access to nanoscale instrumentation and facilities, and the more rapid deployment of nanocellulose science and technology. In combination, these benefits will result in the sustainable and efficient use of America's abundant forest resources, improvements in forest health and conditions, and revitalization of rural economies by creating jobs and boosting the Nation's economy.

USDA/NIFA, universities, professional societies, industry: USDA/NIFA co-sponsored a Workshop on Food Nanotechnology with Purdue University, University of Illinois at Urbana-Champaign, and the Institute of Food Technologists, 25–26 October 2011 in West Lafayette, IN. Multiple academic representatives and food industry R&D leaders participated in the workshop. The primary discussion topics included stakeholder confidence, education and communication, industry perspectives, research needs, and academia–industry cooperation.

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

This NNI goal seeks to broaden and deepen the U.S. emphasis on commercial viability of nanotechnology through development of both practical applications and cost-effective scale-up of nanotechnology-based products and processes. These efforts will capture real benefits for national security, economic development, and job creation. The goal encompasses five objectives[8] that detail how the NNI will increase its investment, focus its resources, and broaden its engagement with academia, industry, and the international community to reach this goal.

The NNI member agencies have a number of activities uniquely targeting technology transfer and commercialization, for example, workshops to obtain input from industry and academia, SBIR and STTR programs to fund innovations in small businesses, and cutting-edge research infrastructure for use by all nanotechnology researchers, including those from industry.

Individual Agency Contributions to Goal 2

DHS: The Science and Technology Directorate at the Department of Homeland Security is focused on the transition of advanced security technologies to DHS operational agencies. The continued development of advanced x-ray sources using carbon nanotube emitters has led to demonstrated improvements in image-based screening prototypes. Nanostructured and microstructured sample collection materials are also currently under evaluation to provide fieldable improvements for explosives trace detection systems.

DOD: Research funded by the Department of Defense that supports technology transfer to commercial products includes the following:

- A new generation of ceramic nanocomposites has been developed that significantly outperforms sapphire as the material of choice for midwave infrared domes for various missile systems. These nanocomposites exceed sapphire's high-temperature strength and thermal shock resistance, are highly transparent in the 3–5 μm atmospheric window, and exhibit 35 times lower emissivity. The nanocomposite domes have reached TRL 5[9] and are under active consideration by several missile program offices. They have undergone seeker systems tests for AIM-9X (Sidewinder) and have been accepted for the next Block program.
- Nanoparticle lubricant (NPL) technology developed at the Air Force Research Laboratory (AFRL) has improved the lifetime ratings of noble metal ohmic contact RF-MEMS switches under development for Air Force and other DOD tactical radios. The AFRL, in collaboration with the University of Dayton Research Institute, synthesized a candidate NPL, and in conjunction with MEMS switch developer XCOM Wireless, developed a deposition process compatible with a production MEMS assembly line. Noble-alloy MEMS relays were tested for hot-switch and cold-switch lifetime at 5 mW and 2 W of continuous RF power at 50 ohms. The relays without NPL performed as expected, within the predicted control performance already characterized for the components. The relays with NPL showed improved lifetimes, from approximately 2x for cold-switched conditions up to nearly 10x for high-power hot-switched conditions, which is a critical leap forward for MEMS technology.
- A recently completed Defense-Wide Manufacturing Science and Technology program with Lockheed Martin's Advanced Technology Center in Palo Alto, CA, has successfully scaled up the manufacturing process of a new nanomaterial to replace current lead-free solders. The Solder Free Electronic Assembly Material (SEAM) program, completed in September 2011, has demonstrated the scalability of copper nanoparticle production necessary for commercial adoption and use. The objective of the SEAM program was to scale the copper nanoparticle fabrication from micrograms per batch to greater quantities necessary for industrial exploitation and adoption. Using a wet chemistry approach, the process is now capable of creating hundreds of grams of nanoparticles in a repeatable fashion. The

[8] For the full descriptions of the objectives of this NNI goal, see the 2011 *National Nanotechnology Initiative Strategic Plan*, http://nano.gov/node/581 or nano.gov/about-nni/what/vision-goals.

[9] The technology readiness level (TRL) system has been adopted by several DOD agencies to help measure progress in R&D activities and programs. TRL 5 is the R&D step "validation in the relevant environment."

copper nanoparticle formulation has a higher thermal and electrical conductivity than alternative lead-free formulations. It also can be processed at a lower temperature (<200°C) than current lead-free solders (~220°C), which makes it attractive for use in emerging component packages and substrates. Additional process development was also performed under the contract to develop a corresponding flux formulation, and it was demonstrated using a commercial aerosol jet dispensation system, resulting in several demonstration articles.

- An Air Force Office of Scientific Research-sponsored team at Stanford's School of Engineering has demonstrated an ultrafast nanoscale light-emitting diode (LED) that is orders of magnitude lower in power consumption than today's laser-based systems and able to transmit data at 10 billion bits per second. This is a major step forward in providing practical ultrafast, low-power light sources for on-chip computer data transmission. The advancement was announced in an article in *Nature Communications*[10] published November 15, 2011. Earlier, the researchers produced a nanoscale laser that was similarly efficient and fast, but that device operated only at temperatures below 150 Kelvin (about 190 degrees below zero Fahrenheit), making it impractical for commercial use. The new device operates at room temperature and could, therefore, represent an important step toward next-generation computer processors. Low-power, electrically controlled light sources are vital for next-generation optical systems to meet the growing energy demands of the computer industry.

- Researchers funded by the Defense Threat Reduction Agency at Emory University have developed a novel nanoporous material for catalytic decontamination using air, by combining polyoxometalates with metal-organic frameworks (MOFs). MOFs are crystalline materials with controllable pore sizes and compositions, with applications such as gas adsorption and catalysis. Challenges remain, however, in using MOFs for catalytic decomposition of chemical warfare agents (CWAs), particularly in stabilizing the MOFs and designing them to work in the ambient environment without requiring additional energy inputs or reagents. Polyoxometalate (POM) compounds are promising catalysts with high oxidative activity, but they require a solid support that will not diminish this activity. The researchers combined the high catalytic activity of a POM with the porosity and selective sorption properties of an MOF. This POM-MOF catalyst showed significantly improved air-based catalytic oxidation of sulfur-containing compounds compared to either the POM or MOF alone. This advancement opens the route for designing similar synergistic compounds for air-based catalytic decomposition of a wide range of CWAs and toxic industrial chemicals.

- The U.S. Army Research Laboratory (ARL) has been carrying out a concerted effort to produce low-cost bulk nanostructured materials for various protection and lethality applications. Some research highlights include the production of bulk nanostructured tungsten for replacing depleted uranium in kinetic energy penetrator applications, development of technologies to stabilize interfaces and grain boundaries to improve the thermal stability of nanomaterials, and severe plastic deformation processing as a cost-effective means to produce nanometals for armor and penetrator applications. ARL has been working on nanoscale *in situ* characterization of microstructure and quasistatic deformation of tantalum and tungsten. ARL has also been involved in several nanomaterials, nanofabrication, and nanotechnology workshops and conferences to promote collaboration.

- The U.S. Army Aviation and Missile Research Development and Engineering Center's Applied Nanotechnology Research Program is a multidisciplinary effort initiated to develop nanoscale structures or components for insertion into advanced missile, aviation, and unmanned aerial or ground vehicle systems. The program is currently focused in four key technology areas: (1) NanoSensors, (2) NanoEnergetics, (3) NanoComposites, and (4) NanoPlasmonics. The overall program objective is to utilize basic and applied research to advance the specific candidate nanotechnologies for successful

---

[10] G. Shambat, B. Ellis, A. Majumdar, J. Petykiewicz, M.A. Mayer, T. Sarmiento, J. Harris, E.E. Haller, and J. Vučković, Ultrafast direct modulation of a single-mode photonic crystal nanocavity light-emitting diode (*Nat Commun* 2:539, 15 Nov. 2011, doi:10.1038/ncomms1543).

transition to technology demonstration programs. Examples of this research and related accomplishments follow:

- o Nanosensors are being developed to detect rocket motor out-gassing and could also be used to detect toxic industrial chemicals. Within the effort, nanotube/nanowire sensors have been developed and tested, various fabrication techniques have been evaluated to improve the selectivity in nanowires, and testing and evaluation of the materials have been accomplished using a customized commercial Raman spectroscopy system.
- o In the area of nanoenergetics, nanomaterials are being developed based on carbon nanotube-doped solid propellants to reduce thermal signatures and eliminate the need for toxic hydrazine, yielding a more environmentally friendly propellant. A related project is evaluating the effects of nano-metallic fuels on the blast performance of enhanced blast explosives. So far the project has identified multiple formulations (doped with carbon nanotubes) that are comparable in performance to standard solid propellants, conducted start-up of an accelerated aging study for formulation, and developed new enhanced blast explosives formulations that replace micrometer-sized aluminum with nanometer-sized aluminum for future antistructural munitions and for combined-effects warheads.
- o Nanocomposites are being explored as reworkable thermoplastic thermal interface materials for missile guidance and seeker electronic interfaces. Samples have been fabricated and tested based on flexible graphite/carbon epoxy interfaces, and multi-wall carbon nanotube coupon samples have been tested for vibration sensitivity.
- o Enhanced nanomaterials are being developed to improve the performance of sensors, electronics, and other missile components, utilizing gallium nanoparticles, especially as a substrate for cresyl fast violet in Raman spectroscopy, for improved longevity, reproducibility, and signal enhancement.

- Nanostructures can provide novel indicators of exposure to radiation in the environment and may in principle be tailored to avoid common false positives. For example, a basic research award to NRL is supporting exploration of gamma-radiation-induced formation of nanoparticles within nanocapsules. This research will investigate the mechanisms by which such interactions reduce silver ions in aqueous solutions. In principle, the fluorescence of resulting nanoparticles could be used to reveal a history of radiation exposure. Such materials present many opportunities for future applications; for example, such nanostructures could be embedded in resins or paints to be used on walls and other coating products.

- In the nanomanufacturing arena, technology transitions and commercialization are being achieved through small business and other programs. Research projects in nanomanufacturing target specific military needs and are designed to enhance warfighter capabilities. Examples of applications are nanotechnology-enabled filtration and biocides for water purification; functionalized carbon nanotube-enhanced composites for increased stiffness, controlled permittivity, and erosion resistance; carbon nanotubes for sealants; nanoparticle-glass coatings for anti-fogging and abrasion resistance; polymer nanocomposites for ballistic windows; metal nanostrands for conductive resins, paints, and electromagnetic-interference shielding; nanotechnology-enabled super-hydrophobic surfaces for damage sensing and self-repairing; CNT-enhanced ultracapacitors for energy storage; nanotube-enhanced silicon for photovoltaics; and nanoparticle- and nanotube-reinforced body armor.

DOE: Across the Department of Energy, basic and applied research offices are working to coordinate research activities in nanotechnology to create a pipeline that supports the advancement of technology from the earliest stages of research towards commercialization, providing an essential link between basic nanoscience discovery and its commercial application.

- Silicon microwire research initially sponsored by DOE's Office of Science progressed in maturity and was picked up by DOE's applied research program at the Solar Energy Technologies Program. This work resulted in a startup company that has raised venture capital and has won an incubator research award from DOE.

- Awardees from DOE's applied programs advance their technologies by utilizing scientific user facilities supported by the Office of Science, including the five Nanoscale Science Research Centers (NSRCs).

- Collaborations between DOE NSRC user facility scientists and industry led to two R&D 100 awards in 2011, with another two R&D 100 awards given for NSRC scientific staff projects.

- DOE/EERE's Advanced Manufacturing Office (AMO, formerly known as the Industrial Technologies Program) pursues nanomanufacturing research, development, and demonstration to substantially reduce the energy embedded in and used by manufactured products. Many of these AMO-funded projects combine the nanotechnology and scale-up expertise of the DOE national laboratories and industry, then use the private sector's resources and capabilities to demonstrate and commercialize the resulting next-generation materials and processes for the global clean energy economy.

  AMO's nanomanufacturing portfolio includes development of nanoparticle-containing fluids to improve lubrication and equipment cooling, scale-up of nanoporous silica insulation for use in steam systems, nanomaterial applications in renewable power generation and energy storage, and optimization of coatings to increase the durability of metal surfaces and components such as those used in power generation and aircraft gas turbines.

  Concept investigations include the use of high magnetic fields as an alternative to high-temperature processing of alloys. Without added heat, this novel process enables the manipulation of atoms to produce nanoscale materials with properties and performance unattainable with conventional processing—thus saving energy.

  Development activities are continuing in superhydrophobic coatings and materials. The national laboratories are working closely with industrial commercialization partners on applications to prevent utility line icing, reduce energy needs for distillation, minimize galvanic corrosion, and decrease the energy needed to move fluids through pipes. AMO's Innovative Manufacturing solicitation conducted during 2011 may result in additional nanotechnology-focused projects.

- ARPA-E's Rare Earth Alternatives in Critical Technologies (REACT) program includes several magnet projects with nanostructure features that leverage exchange coupling to develop the next generation of magnets with limited or no rare earths. REACT also includes the development of superconductor wires with a nanostructure to improve current density. ARPA-E's High Energy Advanced Thermal Storage program has multiple projects that will develop innovative nanomaterials through synthesis, processing, fabrication, and characterization for the development of effective thermal storage for nuclear, electrical grid, and vehicle applications and also for efficient fuel production from sunlight. Highlights include the anticipated development of a thermal storage heat battery that captures and stores energy from the sun to be released onto the grid at a later time using innovative nanomaterials, advanced nanostructured materials to provide a new electric power-driven adsorption cycle for a highly efficient heat pump for electric vehicles, and new composite phase-change materials for heating and cooling applications. ARPA-E's Green Electricity Network Integration program includes a project to develop nanoclay-reinforced ethylene-propylene-rubber for low-cost and high-reliability high-voltage direct current cabling. The Solar Agile Delivery of Electrical Power Technology program includes a project that will develop a new nanoscale magnetic material for energy conversion systems with direct grid connection, which will contribute to efficient, cost-effective, and reliable grid integration of solar photovoltaics.

- DOE/EERE's Vehicle Technology Program funds applied R&D on a variety of nanoscale materials focused on increasing the performance and lowering the cost of vehicle batteries. This work has included the design, construction, and testing of cells and modules for plug-in hybrid electric vehicle and hybrid electric vehicle battery systems based on nanophosphate cathode materials; the development of electro-spinning techniques for producing silicon-coated carbon nanofibers from precursor polymer solutions for lithium-ion battery anodes; and the use of sol-gel processing nanotechnologies to manufacture high-performance carbon electrode materials for use in ultracapacitors.

- Looking forward, understanding of nanotechnology is helping to considerably improve, even revolutionize, many technology and industry sectors from information technology to energy and environmental science. DOE anticipates continued investments in nanotechnology to arise from future funding opportunities.

IC/DNI: The National Reconnaissance Office has made significant progress toward Goal 2, including the following examples:

- Ultra-low-power CNT nonvolatile memory (NRAM) to replace current volatile DRAM memory in data center servers to reduce power consumption of memory by 40–50%. Pilot production with a Fortune 500 company in 2012 will begin the scale-up towards commercial manufacturing.
- Bulk CNT yarns are being transferred to commercial wire and cable companies to replace copper-based cables for spacecraft and aircraft, significantly reducing weight and cost.
- Bulk CNT sheets are being transferred to commercial aerospace companies for electromagnetic interference shielding and electrostatic discharge and lightning protection of aircraft and spacecraft structures and cable harnesses. These sheets reduce weight and enhance performance.
- Quantum dot solar cell technology was transferred in 2012 to a major manufacturer of commercial solar cells. This technology is essential in achieving up to 35% efficiency in space-based solar cells and greater than 40% efficiency in terrestrial solar cells. This will provide up to a 23% increase in power for U.S. satellites.
- Carbon nanotubes as additives for lithium-ion batteries are being transferred to a U.S. commercial battery manufacturer. This nanotechnology additive will improve power density of lithium-ion batteries by as much as 80%.

NASA: For 2012 and 2013, NASA has increased its investment in nanomanufacturing by $2 million, for a total of $3.0 million per year, more than triple the funding in 2011. This increased investment is directly aligned with Goal 2 of the 2011 NNI Strategic Plan and the recommendation of the 2010 PCAST review of the NNI to double the annual Federal investment in nanomanufacturing.

NIH: The NIH fosters the clinical translation of products and practices utilizing a variety of mechanisms. As successful as the Alliance for Nanotechnology in Cancer has been in using nanotechnology to address and solve many important questions in the laboratory, the ultimate measure of the program's success lies in the translation of research discoveries to the clinic. Currently, several nanotechnology-enabled diagnostic and therapeutic agents developed by Alliance investigators are in clinical trials. Examples include:

- A clinical trial evaluating a cyclodextrin-based nanoparticle that safely encapsulates an siRNA agent that shuts down a key enzyme in cancer cells. This open-label, dose-escalating trial is testing the safety of this drug in patients who have become resistant to other chemotherapies.
- A clinical study of targeted nanoparticles that consist of a polymer matrix, therapeutic payloads, functional surface moieties, and targeting ligands, which allow for particle optimization (i.e., accumulation in target tissue, avoidance of being cleared by the immune system, and delivery of drug with the desired release profile). This includes the use of the chemotherapeutic drug docetaxel and a targeting agent in prostate cancer treatment. The Phase 1 study has an ascending, intravenous dose design to assess the safety, tolerability, and pharmacokinetics in patients with solid tumors. The

primary objective of the study is to determine the maximum tolerated dose and to assess preliminary evidence of anti-tumor activity.

In 2011, NCI initiated a public–private industry partnership called TONIC (Translation Of Nanotechnology In Cancer) to promote translational R&D opportunities of nanotechnology-based cancer solutions. An immediate consequence of this effort will be the formation of a consortium involving government and pharmaceutical and biotechnology companies. This consortium will evaluate promising nanotechnology platforms and facilitate their successful translation from academic research to the clinical environment, resulting in safe, timely, effective, and novel diagnosis and treatment options for cancer patients. The TONIC consortium will operate in parallel with the Alliance program and bring together individuals from sufficiently capitalized pharmaceutical, biotechnology, and other healthcare-related companies and startups, which either have ongoing internal efforts or have strategic interest in evaluating the nanotechnology platforms for oncology care solutions, through participating in an academic–private partnership aimed at promoting translational opportunities.

NCI's Small Business Development Center, together with its Office of Cancer Nanotechnology Research, has issued a Funding Opportunity Announcement (open through 2013) that invites SBIR cooperative agreement applications from small businesses that propose to develop new applications or to improve existing application(s) of nanotechnology-based therapeutics and/or *in vivo* diagnostics. This funding opportunity specifically supports preclinical optimization and testing of these cancer-relevant nanotechnology applications against the intended cancer type. The outcomes are expected to advance the discovery and preclinical optimization phase so that an Investigational New Drug (IND) or Investigational Device Exemption (IDE) application could be submitted to FDA by the end or shortly after completion of the Phase II project period.

Research funded by the National Human Genome Research Institute (NHGRI) in 2011 is supporting significant advances in nanotechnology-based DNA sequencing. It has the potential to overcome fundamental shortcomings in current sequencing methods and thus to enable a key missing component required for individualized medicine. These technologies are the only ones likely in the near term to produce highly sought, very long sequence reads and that can directly identify epigenetic modifications on the DNA, which are deeply implicated in biological development and in diseases such as cancer. A first nanotechnology-based sequencing method was commercialized in 2011 and is currently producing data that are helping to answer important biomedical questions. Challenges to developing a second approach—nanopore-based sequencing devices—were recently reviewed by a group of investigators supported by an NIH sequencing technology initiative.[11] Over the past year several key advances have been achieved, including new ways to precisely control the motion of a DNA molecule through a nanopore sensor; a deeper understanding of the physics of translocation control and sensing; demonstration of sensing of single-base translocations and of sensing to distinguish among the DNA subunits (nucleotides) by alternate sensing technologies; and demonstration of methods with which to produces arrays of nanopores to increase device throughput. Anticipated breakthroughs in the next year increase the likelihood of achieving revolutionary functional devices in the very near future.

NIST: The NIST Center for Nanoscale Science and Technology user facility fosters nanotechnology transfer through the use of a state-of-the-art commercial toolset made available with industry-friendly access and intellectual property policies, and by developing and disseminating new nanofabrication processes and measurement methods. Since the center was established in 2007, the number of industrial research

[11] See David Branton et al., The potential and challenges of nanopore sequencing, *Nature Biotechnology* 26, 1146–1153 (2008), doi:10.1038/nbt.1495.

participants has grown rapidly, representing over 80 companies in 2011. R&D can be done by individual users or with the assistance of a technical expert from the staff, imparting the flexibility needed to satisfy the widest range of needs, from expert academic researchers to small companies with innovative new technologies but limited expertise in nanofabrication.

NRC: The U.S. Nuclear Regulatory Commission 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 for the NRC to better carry out its oversight role.

NSF: In 2011 and 2012 NSF continues its contributions to translational innovation programs, including GOALI (Grant Opportunities for Academic Liaison with Industry), I/UCRC (Industry & University Cooperative Research Centers), Innovation Corps program (www.nsf.gov/funding/pgm_summ.jsp?pims_id=504672), and an umbrella program, PFI (Partnerships for Innovation), which includes two complementary subprograms: AIR (Accelerating Innovation Research) and BIC (Building Innovation Capacity). NSF also continues its support of technology transfer in nanotechnology through core programs, primarily through investments in centers such as NSECs, NCN, Materials Research Science and Engineering Centers (MRSECs), Centers for Chemical Innovation (CCI), and others. NSF's Innovation Corps Program is being initiated in 2012 with the objective of developing and nurturing a national innovation ecosystem that builds upon fundamental research to guide the output of scientific discoveries closer to the development of technologies, products, and processes that benefit society.

For 2013, NSF plans continued emphasis on technology transfer through core programs, primarily through centers investments (NSEC, MRSEC, NCN, NNIN, CCI, others). It will also continue its investments in the GOALI, I/UCRC, AIR, BIC, and Innovation Corps programs.

Examples of recent NSF projects in support of Goal 2 include the following:

- *Nanophotonics Speeds up Multi-Core Networks*. Researchers at the Computer Science and Artificial Intelligence Laboratory at the Massachusetts Institute of Technology (MIT) are attempting to solve the multi-core programming crisis by using high-performance on-chip networks. Recent advances in the field of nanophotonics will soon allow optical communication devices to be integrated into standard microprocessor fabrication processes. The MIT group is investigating ways to use these devices to build energy-efficient, high-performance networks that allow hundreds (or thousands) of processing cores to work together. The ATAC (All-To-All Computing) processor architecture employs optical waveguides that snake through the entire chip and allow data to propagate quickly to all cores within it. Because optical signals travel faster than electrical signals, they enable efficient global broadcast and eliminate the distance-based latencies common to large, multi-core processors. These innovations have the potential to dramatically increase the effectiveness and usability of future microprocessors.
- *Speedier Nanotube Circuits*. Progress continues in the development of faster nanotube circuits to be used in complex integrated circuits. Stanford University researchers have improved a stamping technique used to transfer nanotubes grown on quartz to a silicon dioxide wafer for fabrication into transistor arrays and circuits. The previous technique allowed only one transfer step before the nanotubes became tangled. By adding additional deposition and etching steps to the stamping, the number of transfer steps has been increased to 20.

USDA/FS: The USDA Forest Service is contributing to the transfer of new technologies into products for commercial and public benefit by matching its mission-related goals against forest products industry goals and priorities for nanocellulose commercialization, and then investing in activities that serve the high-priority goals of both parties. Current industry infrastructure to harvest, collect, and process certified sustainable trees can provide a platform for rapid scale-up and commercialization of new materials and products. By interacting with the forest products industry through its Agenda 2020 Technology Alliance, USDA/FS obtains more efficient and effective use of resources through modern industry technology R&D project management practices. As a result, the pathway from basic research to commercialization has been laid out. Along this pathway, one very important step for rapidly commercializing nanocellulosic materials is to have uniform and repeatable amounts of the main types of nanocellulosic materials available in sufficient quantities to support university and government laboratory researchers' needs as well as industry's needs for product application and development exploration. This allows activities along the pathway to commercialization to be carried out in parallel rather than serially.

The USDA/FS has invested in facilities to produce both cellulose nanofibers (CNFs) and cellulose nanocrystals (CNCs) in larger than laboratory bench-scale quantities. USDA/FS is installing CNC production facilities at its Madison, WI, location to produce 35–40 kg of CNCs every three working days. In addition, USDA/FS has entered into a longer-term memorandum of understanding with the University of Maine–Orono to install facilities to produce 100+ kg of CNFs per working day. These materials will be available to researchers at universities, government laboratories, and industry to support fundamental and applications research and small-scale product development. In addition, the facilities are of such size that they will allow for process development R&D to occur. The two facilities are scheduled to become operational in either late first quarter or early second quarter of 2012. FS scientists are also evaluating the patentability of manufacturing nanocellulose from biorefinery processes developed by FS scientists.

USDA/NIFA: The NIFA SBIR program will continue broadly supporting innovation using nanotechnology in agriculture and food applications.

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 ability to provide 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 continues to host 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 also continues to provide in-depth nanotechnology-specific training events for USPTO patent examiners to enhance their technical knowledge base. As a result of this ongoing training initiative and targeted hiring of patent examiners with specific nanotechnology experience, the 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, international standards bodies: Technical experts from multiple agencies, including DOD, DOE, EPA, FDA, NCI, NIOSH, NIST, and USDA/FS, are working to develop 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). NNI agencies are also participating in standards development activities within ASTM International Committee E56 (Nanotechnology), International Electrotechnical Commission Technical Committee 113 (Nanotechnology Standardization for Electrical and Electronics Products and Systems), and the Organisation for Economic Cooperation and Development's Working Party on Manufactured Nanomaterials. This close cooperation with international standards organizations contributes U.S. expertise and helps NNI member agencies provide input into U.S. priorities in the international standards arena.

NNI member agencies, Organisation for Economic Co-operation and Development (OECD): The Department of State has 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).

DOC/BIS, other NNI agencies, industry: The Bureau of Industry and Security (BIS) of the Department of Commerce has primary responsibility, in coordination with several other agencies, for implementing U.S. export control policy on dual-use commodities, software, and technology, including nanotechnology. BIS consults closely with industry on the development of regulatory policy through its Technical Advisory Committees, which provide valuable industry input on trends in technologies and the practicality and likely impact of export controls.

IC/DNI, NASA, Air Force: A workshop entitled "Carbon Nanotubes for Space Applications Interchange" was sponsored by these agencies in 2011. It involved research and product updates, as well as ongoing discussions to coordinate future research activities in this area. The meeting engaged both government and industry communities in reviewing several promising technical approaches to use of CNT materials in space applications.

NIH/NCI, FDA, private research organizations, the general public: The translational aspects of nanotechnology-related research associated with imaging were highlighted at the Image-Guided Drug Delivery hot topic session of the 2011 Radiological Society of North America Annual Meeting. This follows from the April 2010 NCI Symposium on Image-Guided Drug Delivery, held in affiliation with the American Association for Cancer Research (see *Cancer Research* 2011; 71:314–317). NCI also conducted a similar workshop on Image-Guided Targeted Delivery in Cancer in November 2010. These workshops brought together basic and clinical scientists with expertise in molecular imaging and targeting.

NIH/NCI, NIST, FDA, academia, industry, international standards organizations: Since 2004 the NCI has been actively involved in the standardization of the preclinical characterization process for nanomaterials intended for cancer applications. This effort is led by the Nanotechnology Characterization Laboratory (NCL), which was formed by the NCI Alliance for Nanotechnology in Cancer. The NCL is a formal interagency collaboration between NCI, NIST, and the FDA that serves as a national resource and knowledge base for cancer researchers, and that facilitates the development and translation of nanoscale particles and devices for clinical applications. The NCL's services are available free of charge to researchers from academia, government, and industry who are developing nanotechnology-based cancer diagnostics, imaging agents, and therapeutics. Researchers must apply to utilize the NCL and, if their application is accepted, the nanomaterial is submitted to the NCL for characterization. Prior to acceptance, candidate nanomaterials may be evaluated for previously demonstrated efficacy in *in vitro* and/or in animal models, for advantages offered by the strategy over existing cancer therapies or diagnostics, and other criteria.

Over the last seven years, the NCL has established a three-tiered assay cascade of tests for nanomedicine safety and efficacy. The laboratory has evaluated over 240 different nanoparticle formulations, with results published in scientific journals and included in prospective IND and IDE applications with the FDA. The NCL has collaborated with organizations such as ASTM and ISO to standardize several of its assays to be used in laboratories across the country. These accomplishments have established the NCL as a recognized leader in the field of nanomaterial characterization.

NIST, DOC, other Federal agencies, industry, academia: NIST, in collaboration with other DOC components and agencies, is establishing the National Program Office for the Advanced Manufacturing

Partnership (AMP). AMP is an effort initiated by the White House that brings together industry, academia, and the Federal Government to drive investments in emerging technologies (including nanotechnology) that will create high-quality manufacturing jobs and enhance U.S. competitiveness. The AMP National Program Office will include participation from all Federal agencies involved in U.S. manufacturing to support interagency coordination of advanced manufacturing programs and to provide a link to the growing number of private-sector partnerships between manufacturers, universities, state and local governments, and other manufacturing-related organizations.

NIST, DOE. NIST is developing low-cost optical methods jointly with DOE to enable industrial process control of platinum loading in fuel cell membranes, which will reduce platinum waste and thus decrease manufacturing costs. These optical methods will help enable improved process control for alternative energy generation and storage where manufacturing costs of nanostructured materials directly affect U.S. competitiveness.

NIST, industry: Under a cooperative research and development agreement, NIST is working with a small pharmaceutical company, Aparna BioSciences, to develop measurement and characterization methods critical for the controlled manufacture of nanoparticles for targeted drug delivery.

NIST, other Federal agencies, the American National Standards Institute: In 2011 an International Workshop on Challenges to the Increased Use of Documentary Nanotechnology Standards brought together leaders from U.S. and international standards organizations, other U.S. agencies (including CPSC, DOE, EPA, FDA, and NIH), industry, and nongovernmental organizations, as well as U.S. Government representatives from OMB, OSTP, the Office of the U.S. Trade Representative, the U.S. House of Representatives, the General Services Administration, and the Government Accountability Office, to discuss the state and usage of documentary standards for nanotechnology.

NSF, industry: NSF's NSECs have generated numerous spin-off companies, many of which are users of the NNIN facilities. The new NSF Engineering Research Centers on Nanosystems (solicitation in 2011 and awards expected in 2012) have a specific focus on interactions with industry.

USDA/FS, industry: In order to facilitate commercialization, remove trade barriers, and provide harmonized information for regulators, it is critically important to develop internationally accepted standards for the description and use of nanomaterials derived from forest products. USDA/FS co-organized and co-led an international workshop with the Technical Association of the Pulp and Paper Industry (TAPPI) on International Standards for Nanocellulose, June 9, 2011, in Arlington, VA. The workshop dealt with standards for nanocellulose, including standards focused on environmental, health, and safety (EHS) determinations. It was agreed that planning and coordination for international standards development would start immediately and that a roadmap for creating these standards would be developed as part of the workshop proceedings. Due to its overarching nature, ISO Technical Committee 229 (TC 229, Nanotechnologies) was targeted as the primary organization to submit standards-developing projects for nanocellulose. Key participants and contributors to the workshop roadmap have formed an International Nanocellulose Standards Coordination Committee (INSCC). TAPPI in the United States will house the INSCC and provide the necessary support to carry out this roadmap. Under the TAPPI organization, this roadmap will be updated periodically to reflect the advancement of wood-derived nanomaterials science, EHS determinations, and responsible product development.

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 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

This NNI goal seeks to develop all aspects of the infrastructure necessary to the advancement of nanotechnology-based knowledge, products, and practices that will benefit the Nation and its citizens. The goal encompasses three objectives[12] that detail how the NNI will responsibly engage and educate the public and the workforce regarding the opportunities that nanotechnology offers and the skills it requires, along with providing the needed access to advanced facilities and tools.

Significant progress is being made on all three aspects of Goal 3 (developing and sustaining 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 that target K–16 education, improve nanotechnology curricula in U.S. schools and universities, and educate the public about nanotechnology are growing in scale and reach (see details below). Development of the extensive network of research centers, user facilities, and other infrastructure for nanotechnology research, a key element of the original NNI strategy, is now largely complete, although there are ongoing investments to maintain the equipment and facilities at the cutting edge.[13]

Individual Agency Contributions to Goal 3

DOD: The DOD Basic Research Sciences programs help to produce 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. Advanced instrumentation and novel techniques used in some projects also may improve our ability to do the research itself. Applied research and advanced development programs also contribute to the human and instrumentation infrastructure critical for future progress in nanotechnology and nanotechnology-based products. Some examples of such research follow.

- The Tip-Based Nanofabrication program at DARPA is developing methods for controlled nanomanufacturing—by leveraging arrays of tips or optical techniques—to fabricate structures with nanometer-scale control.
- The DARPA NanoThermal Interfaces program is conducting end-to-end redesign of thermal management approaches (a key enabler for high-power military systems) through the exploration and optimization of new nanostructured materials for two-phase heat spreaders, air-cooled exchangers, and thermal interface materials.
- The DARPA Quantum Orbital Resonance Spectroscopy program is developing a novel magnetic resonance imaging technique without a superconducting magnet. The program develops imaging techniques that will work down to tens to hundreds of nanometers using unique quantum mechanical aspects of photons.

---

[12] For the full descriptions of the objectives of this NNI goal, see the 2011 *National Nanotechnology Initiative Strategic Plan*, http://nano.gov/node/581 or nano.gov/about-nni/what/vision-goals.

[13] See a detailed discussion of the U.S. NNI infrastructure in the NNI Supplement to the President's FY 2008 Budget, 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 nano.gov/centers-networks.

The Air Force supports many academic institutions, including the University of Dayton and Wright State University. Several different programs within these universities allow for students to earn graduate degrees in engineering, physics, and biology while working with the Air Force. In addition to its local collaborations, the Air Force also works with universities such as University of Toledo, Case Western University, Otterbein, Ohio State University, MIT, University of Oregon, and Jackson State University. The DOD has a vested interest in mentoring students of all levels during their education. The Air Force summer student program highlights this interest and demonstrates involvement of students at the high school level up to the graduate school level. Students are paired with research mentors and are assigned research projects with defined hypotheses in order to teach them about the scientific method. At the end of the summer, students present their research at a Summer Student Intern Day. The students are supported through a variety of focused programs within the DOD and Air Force overall research arena.

DOE: The Department of Energy supports five Nanoscale Science Research Centers (NSRCs), user facilities operated for the advancement and acceleration of leading-edge nanoscale science and engineering R&D. The NSRCs are inherently multidisciplinary user facilities providing access to state-of-the-art instrumentation and unique capabilities for the synthesis, processing, fabrication, analysis, theory, and modeling of nanoscale materials, as well as world-leading scientific expertise. Each NSRC has distinct scientific themes for its internal staff science program[14] and supports a wide range of user activities across the spectrum of nanoscale science, engineering, and technology, including unique instruments and capabilities developed in-house that are made available to users.

DOEd: The Department of Education supports nanotechnology as an important development in science, technology, engineering, and mathematics (STEM) education. The agency is becoming aware of the increasing importance of nanotechnology to economic development. For example, the Office of Adult and Vocational Education aims to introduce nanotechnology as part of the STEM Career Cluster.

FDA: In 2011 and 2012, FDA training revolved around course work and lectures by experts in science and regulatory issues surrounding nanotechnology. In 2013, FDA will continue to provide training, including laboratory training with analytical equipment used to characterize the physical and chemical properties of engineered nanomaterials relevant to FDA review of products that may contain nanomaterials or otherwise involve nanotechnology. This type of training is valuable to FDA staff members who review product applications that include data derived from such instrumentation.

IC/DNI: The National Reconnaissance Office has competitively selected IC postdoctoral researchers to work on nanotechnology challenges to advance the state of the art of lithium-ion batteries for 2012 through 2014. Funding was provided by the Office of the Director of National Intelligence.

NASA: NASA's Office of the Chief Technologist initiated the Space Technology Research Fellowship (STRF) Program in 2011 to create a pipeline of highly skilled scientists and engineers needed for NASA's and the Nation's technological future. In 2011, 80 fellowships were awarded in STEM fields, including seven fellowships in nanotechnology. The Space Technology Research Fellowships provide up to four years of funding for PhD students and two years of support for MS students to perform collaborative research with NASA centers and other Federal laboratories in support of the technology needs identified in the fourteen Space Technology Roadmaps. A solicitation was released in December 2011 for a second round of fellowships that are planned to start in August 2012. While the exact number of total awards and the number of awards in nanotechnology-related areas has not been determined, it is anticipated that a significant number of STRFs awarded in 2012 will be in nanotechnology- and nanoscience-related fields. Furthermore, many of the awards made outside this fellowship program involve academic institutions, at least as co-investigators, and that involvement can include support for graduate students and

[14] science.energy.gov/bes/suf/user-facilities/nanoscale-science-research-centers

undergraduates. NASA's engagement with academia in technology development across a range of technological maturity adds depth to the educational experience of the students involved.

NIH/NCI: In 2010, with the renewal of the NCI's Alliance for Nanotechnology in Cancer program through August 2015, the training component was 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 students and postdoctoral researchers with broad backgrounds in medicine, biology, and other health sciences as well as in the physical sciences, chemistry, and engineering. The K99/R00 grants support the transition of postdoctoral scientists working on cancer nanotechnology from mentored environments to independence. The K99/R00 trainees are provided the necessary multidisciplinary training to prepare for careers in cancer nanotechnology research, as well as to establish independent research programs in the field. The CNTC 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, the CNTCs will offer both short courses and workshops as well as outreach experiences.

NIST: In 2013, the NIST Center for Neutron Research (NCNR) user facility will be in its first year of operations with new measurement capabilities, including a new small-angle neutron scattering instrument for probing the structure of soft materials, and a neutron reflectometry instrument representing a new, very sensitive probe that yields unprecedented information on nanostructured materials. In addition to the new measurement capabilities provided by the recent NCNR expansion, the NCNR is developing a new type of neutron detector promising orders-of-magnitude increases in detection efficiency. Beginning in 2012, NIST will invest additional funds to design and build a new detector capable of distinguishing multiple wavelengths of scattered neutrons simultaneously, which will permit types of measurements on nanostructured materials not currently possible using continuous neutron sources.

Beginning in 2012, the CNST will substantially increase the portion of its annual budget devoted to recapitalizing and updating the user facility's equipment and instrumentation, thereby maintaining the cutting-edge research environment required to meet the nanoscale measurement and fabrication needs of industry and other stakeholders.

NIST is expanding its efforts to create a skilled nanotechnology workforce through cooperative agreements with academic institutions supporting postdoctoral researchers and visiting fellows, additional National Research Council Postdoctoral Research Associates, and outreach activities such as lectures at the annual NIST Summer Institute for Middle School Science Teachers.

NSF: NSF programs described throughout this report support the training and education in nanoscale science and engineering of about 10,000 students and teachers per year. In particular, the NISE, NSEC, NCN, MRSEC, and Engineering Research Center (ERC) projects contribute to nanotechnology education.

The Nanotechnology Undergraduate Education (NUE) Program was initiated in 2003 as a component in the NSF Nanoscale Science and Engineering Program. Nanotechnology and nanoengineering already has had an impact on biomedical technology, computers, consumer products, electronics, energy, the environment, materials, and pharmaceuticals. There is a growing need for engineers who can fill several roles that are required to transform nanotechnology from intriguing science to useful technology. Nanosystems engineers will be needed to educate and support potential nanotechnology end users, transition laboratory work into commercial production, evaluate the commercial viability of products, create new nanotechnology companies, and interface between scientific researchers and investors. Hence, in 2007 the NUE program name was modified to "Nanotechnology Undergraduate Education in Engineering." The objective of the NUE in Engineering program is to integrate nanoscale science, engineering, and technology into undergraduate engineering curricula. Funds are provided for projects that will address the educational challenges of these emerging fields and generate practical ways of introducing nanotechnology into undergraduate engineering education, with a focus on devices and systems and/or on social, economic, and ethical issues relevant to nanotechnology. The NUE in Engineering program emphasizes new approaches to undergraduate engineering education through interdisciplinary collaborations. These collaborations could lead to, but are not limited to:

- New examples of undergraduate nanoscale engineering courses that are presented through the development of laboratory and demonstration experiments, manuals and other written materials, software, and web-based resources
- Development and dissemination of new teaching modules for nanoscale engineering of relevance to engineering education that can be used in existing undergraduate courses
- Incorporation of undergraduate research opportunities in nanoscale engineering into the curriculum at any level
- Development of courses or curricular enhancements related to nanoscale engineering and technology and environmental or social change

The NUE in Engineering program is a multi-directorate program involving support from all divisions within the Directorate for Engineering, the Division of Undergraduate Education in the Directorate for Education and Human Resources, and the Division of Social and Economic Sciences in the Directorate for Social, Behavioral, and Economic Sciences. The NUE program is now completing its ninth year. The program has thus far provided $23.8 million in support for 155 projects to many diverse types of institutions, from small colleges to large research universities and historically black colleges and universities. NUE awards are in three areas: (1) curriculum/course development, (2) laboratories and/or modules development, and (3) ethical, societal, economic, and environmental implications of nanotechnology.

NSF provides support to universities for the development of nanotechnology—and related broad educational activities—through the National Nanotechnology Infrastructure Network. The NNIN is an integrated partnership of fourteen user facilities providing unparalleled opportunities for nanoscience and nanotechnology research. The network provides extensive support in nanoscale fabrication, synthesis, characterization, modeling, design, computation, and hands-on training in an open, hands-on environment available to all qualified users.

NNIN Education Goals. NNIN has as its goals a wide variety of educational outreach that spans the spectrum of "K–gray," i.e., school-aged children through adults. Education and outreach components of the NNIN include network-wide programs to address needs at the national scale, along with more specific efforts for communities that are local to network sites. The NNIN has established the following goals for its network-based educational outreach and training:

- Expose young people to advanced and exciting research in nanotechnology and motivate them to educate themselves for careers in the sciences or engineering
- Train teachers and guidance counselors about the discipline of experimental sciences, provide additional teaching tools, and enhance their enthusiasm for having students pursue careers in science
- Create and distribute educational materials for children, college students, technical professionals, teachers, and the general population, as well as improve their understanding of and involvement with science, technology, engineering, and mathematics

- Focus these efforts on population segments having disproportionately low employment and education in sciences, including women, disadvantaged minorities, and the economically disadvantaged

The NNIN education activities are coordinated at the Georgia Institute of Technology site, but all NNIN sites are participating in various ways. The NNIN also conducts one of the largest and most successful Research Experience for Undergraduates (REU) programs in nanotechnology. Students are assigned to a specific research project and make a meaningful research contribution to their research groups with support from faculty, graduate student mentors, and facility staff. Each project involves hands-on nanotechnology research with state-of-the-art equipment. Descriptions of the 2011 NNIN (REU) research accomplishments may be found at www.nnin.org/nnin_2011reu.html. Highlights include the following:

- An engineering faculty member at the Colorado School of Mines (CSM) has received an NUE grant that was partly funded NSF's Directorate for Social, Behavioral & Economic Sciences. The central goal of the project is to develop and implement interdisciplinary learning on societal, ethical, economic, and environmental issues associated with nanotechnology. The course material will be incorporated in the humanities and social sciences curriculum, and this will be done at all undergraduate levels. One objective is to develop a two week module introducing these issues in a first-year course, Nature and Human Values, which is required for all undergraduates at CSM. The module will introduce key nanotechnology in society issues by emphasizing one or two case studies of contested issues that serve as a focus in the lectures, for discussion in the weekly seminars, and for reading and writing assignments.

- An historian at the Chemical Heritage Foundation has received a grant to determine how materials science serves as one of the "constituent communities" of nanotechnology. Beginning in the 1980s, the field of nanotechnology emerged as an amalgam of related disciplines in the physical sciences and related technologies, including physics, chemistry, surface science, microelectronics, and materials science. Focusing on one important lineage in nanotechnology's genealogy, this project will assess the continuities and discontinuities in the institutions and communities of materials research as the field recasts its identity in the late 20th and early 21st centuries. The study will provide valuable clues for understanding and evaluating the performance of Federally funded interdisciplinary research centers prevalent today.

USDA/FS: The Technical Association of the Pulp and Paper Industry, the forest products industry through the Agenda 2020 Technology Alliance (A2020), and USDA/FS are working together to develop within the TAPPI organization a nanocellulose-focused division to advance the science and technology supporting the use of nanocellulose and other renewable nanomaterials; recruit and develop a skilled workforce; and develop, share, and disseminate knowledge and information needed for the development and deployment of renewable nanomaterials. TAPPI serves as the leading nonprofit, volunteer-led technical nongovernmental organization for the U.S. and worldwide pulp, paper, paperboard, and converting industries.[15] TAPPI creates networks and educational and other professional growth opportunities for its professional members and university student chapters. It publishes technical journals, books, and technical manuals; organizes professional and university student chapters; organizes and conducts webinars and symposiums; and develops materials standards. The TAPPI Nanotechnology Division began formal operations in 2011. The USDA/FS co-sponsors TAPPI scientific conferences and participates in developing and carrying out TAPPI's array of other activities aimed at creating educational materials, engaging professional members and university students, and promoting the underlying science and technology supporting use of nanocellulosic materials.

---

[15] The converting industry uses paper and paperboard to make products such as laminates, boxes, bags, and other types of shipping containers.

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

DOEd, NSF: The DOEd Office of Vocational and Adult Education (OVAE) partners with NSF's Advanced Technological Education (ATE) program, which includes nanotechnology. That partnership has been examining the usefulness of OVAE's documentation of "Rigorous Programs of Study" for ATE awardees. OVAE wants to learn from examples of what it views as the appropriate way to develop and implement programs of rigorous study (e.g., how its theory may play out in practical conditions), and NSF wants to try out OVAE's theory to see how it adds to what NSF's awardees are doing organically.

NIH/NCI, GRC: In 2011, the NCI organized the first annual Gordon Research Conference (GRC) on Cancer Nanotechnology, which was held in Waterville, ME, during the week of 17–22 July 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 brought together an outstanding and diverse group of scientists from the clinical, biological, and physical sciences, as well as postdoctoral fellows and graduate students. This conference will take place again in 2013.

NIH/NHLBI, academia: The National Heart, Lung, and Blood Institute Programs of Excellence in Nanotechnology contain skills development components that seek to produce graduate students and fellows with multidisciplinary skill sets encompassing disease treatment and diagnosis as well as nanotechnology. The PENs also have outreach activities that provide K–12 students and teachers with hands-on introductions to nanotechnology.

NSF, 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. NSF awards supplements for student participation in the Sandia "National Institute for Nano-Engineering" Summer Scholars Program.

Goal 4: Support responsible development of nanotechnology

This NNI goal, of equal importance to the other three pillars of the NNI framework, integrates the pursuit of world-class nanotechnology development with sustainable and responsible research, development, and commercialization practices. The goal encompasses four objectives[16] that detail how the NNI will address safety and risk issues across the life cycles of nanomaterials; foster productive and ongoing domestic and international dialogues on best practices in nanotechnology development; proactively address ethical, legal, and social issues associated with nanotechnology development; and apply best practices at all levels to ensure that nanotechnology benefits society and the environment over the long term. These objectives are fully consistent with the research aims detailed in the 2011 NNI Environmental, Safety, and Health Research Strategy (nano.gov/node/681).

The NNI is making 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 $105 million in the 2013

---

[16] For the full descriptions of the objectives of this NNI goal, see the 2011 *National Nanotechnology Initiative Strategic Plan*, http://nano.gov/node/581, or nano.gov/about-nni/what/vision-goals.

request. This funding only includes 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 issues (ELSI) related to nanotechnology.

Individual Agency Contributions to Goal 4

DOD: Although the Department of Defense 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. DOD is working closely with the NSET Subcommittee and its working groups, including the Nanotechnology Environmental and Health Implications Working Group, and DOD is actively seeking additional collaborative opportunities in this area with other Federal agencies. DOD considers EHS 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. 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 harmful chemicals in the environment. Examples of such research follow.

- While initial nanotoxicity studies focused mainly on the size of the ENM, as the field has progressed, researchers have begun investigating other parameters than just size. Research at AFRL has focused on evaluating the interaction of ENMs in relation to size, shape, surface charge, and surface chemistry. AFRL has established that gold ENMs mediate their cytotoxic response through size, charge, and shape. In addition, studies performed using aluminum and aluminum oxide nanoparticles in a lung co-culture model to simulate inhalation exposure demonstrated that the surface coating did not impact viability, but it did have an effect on phagocytic activity in macrophages, with the aluminum nanoparticles causing a significant decrease in phagocytosis. Collectively, these results demonstrate that other characteristics of ENMs apart from size contribute to nanotoxicity. Therefore, a systematic evaluation of physicochemical properties in relation to toxicity is essential for the assessing the risk of ENMs.
- The Air Force has been recognized for its lead in pursuing the link between nanomaterial physical characterization and the determination of biological effects. Early nanomaterial studies were criticized for inconsistency and lack of reproducibility. These discrepancies were due largely to the fact that because nanomaterials possess highly unique physical parameters, these physical aspects must be fully characterized before any biological evaluations can be made. Initial characterization studies performed and published by AFRL have guided the nanotoxicology community to recognize the importance of physical parameters, and journals are now requiring proper characterization for publication, thereby increasing the overall quality and accuracy of the studies published in the field of nanotoxicology.
- In nanotoxicology studies performed by the Air Force, two different co-culture models have been developed to evaluate nanomaterial exposure. Since inhalation is the most likely exposure scenario, researchers developed a lung co-culture model to evaluate the effects on lung epithelial and lung immune cells. Specific evaluations of aluminum nanoparticles in the lung co-culture model were published by the American Chemical Society (*ACS Nano*) demonstrating the effect of nanosized aluminum on immune function. This lung co-culture model has been transitioned as a model for quickly screening jet fuel toxicity as well as nanomaterial toxicity. In addition to respiratory studies, research has also focused on the neurological implications of nanomaterial exposure. Within AFRL, a neuronal co-culture has been established that incorporates brain-derived neurons and the brain immune cells (microglia). Preliminary studies using manganese (a known neurotoxicant) and

manganese nanoparticles have validated the use of this model for nanotoxicity studies. Other metallic nanoparticles relevant in DOD and Air Force applications are being evaluated currently.

- In addition to establishing key protocols for characterization and *in vitro* studies, AFRL also has contributed to the evaluation of nanomaterial uptake and localization. It has demonstrated the use of ultraresolution microscopy in conjunction with fluorescence microscopy to image metallic nanoparticles. This achievement was highlighted in the *International Journal of Toxicology*. Furthermore, AFRL identified procedures to enhance TEM measurements by incorporating elemental analysis to ensure that the visualized materials are the nanomaterials of interest and not artifacts of TEM preparation. In addition to verifying uptake, the TEM images can also provide information on aggregation patterns following uptake as well as changes in primary nanomaterial morphology and size.

- The Army is conducting research to support the safe development of military applications of nanotechnology. Its nanomaterials research focuses on the potential hazards that nanomaterials pose to the environment over the life cycle of the technology. The research is vital in improving soldier safety by avoidance of potential health threats in training operations, sustaining training facilities and installations, providing cost savings through proactive environmental management of nanomaterials, reducing environmental and regulatory constraints, and improving speed and safety for fielding new nanomaterial-dependent technologies. Examples of this research and related accomplishments include the following:
    - The Army Corps of Engineers has led the development and refinement of sensitive and selective methods to detect and measure nanomaterials in the environment at environmentally relevant concentrations. Novel techniques, including hyperspectral spectroscopy, particle separation, and x-ray based technologies, have been used to characterize particle attributes in water, soil, and tissues.
    - The Army is developing a Nanomaterials Experiment-based Predictor of Environmental Risk and Toxicity (NanoExPERT), a predictive model that technology developers can use to access data and model predictions on a material’s properties, fate, and toxicity. Decision analysis techniques are being developed to support research and development of nanotechnologies. Multicriteria Decision Analysis and Value of Information are used to prioritize research to address various nanotechnology needs. These techniques have been applied to military technology developers in specific case studies using nano-aluminum, nano-titanium, quantum dots, and carbon nanotubes.

- Researchers at Yale University funded by the Defense Threat Reduction Agency's Chemical and Biological Technologies Directorate are developing a novel approach for the real-time detection of biomarkers, biological threats, and pathogens without requiring amplification. Silicon nanowire sensors are used to show unprecedented sensitivity and selectivity, sensing down to attomolar concentrations (10^{-18} mol/L, equivalent to one grain of salt in an Olympic-size swimming pool), and detecting cancer biomarkers in whole blood at physiologically relevant levels. Because of the use of industry-standard fabrication, the system is robust, manufacturable, and affordable. The technology can be multiplexed for greater accuracy and precision to eliminate false positives and to screen for multiple biomarkers, enabling entire assays to be done with a single drop of blood. Another potential application of this technology is screening of bacterial pathogens for food- and water-borne diseases.

- DOD understands fully the value of coordination and collaboration across DOD and with other agencies and institutions. For this nanomaterials research, collaborations have focused on leveraging resources, expertise, and analytical capabilities. Within DOD, the Air Force and Army are coordinating research on nanotoxicity and prediction of nanomaterials health effects. This research has focused on *in vitro* toxicity of nanomaterials and the use of this information for predictive modeling of the safety and health effects of nanomaterials.

EPA: The 2013 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 nanomaterial physicochemical properties influence both fate and effects so that general trends in nanomaterial implications can be ascertained. Coupled with research using sustainable chemistry and life-cycle-based assessment, this work will inform a more cost-effective and sustainable approach to nanomaterial production and management. In addition, the fate and ecological and toxicological effects of selected nanomaterials are under examination. EPA has integrated nanomaterials EHS research within its ongoing chemicals research under the Chemical Safety for Sustainability research program (CSS; see www.epa.gov/ord/priorities/chemicalsafety.htm). This integrated approach should lead to benefits in both nanomaterial and chemical EHS research and in sustainability research. The CSS program builds on the needs identified in EPA's Nanomaterial Research Strategy (www.epa.gov/nanoscience) and is consistent with the scientific needs identified in the 2007 EPA Nanotechnology White Paper (www.epa.gov/osa/nanotech.htm) and the 2011 NNI EHS Research Strategy.

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 harmful impacts of nanomaterials. The goal is to foster technological advances that maximize benefits to society by minimizing environmental impacts.

The environmental fate, exposure, and toxicological effects of selected nanomaterials are under examination. These investigations are focused on a core set of EPA-relevant nanomaterials that represent carbon-, metal-, and metal oxide-based products. New and existing analytical methods will be developed and/or refined to measure and evaluate quantities and characteristics of relevant nanoparticles in environmental and biological media, and to allow for distinguishing among various forms of these nanoparticles and their degradation products. Additionally, these methods will assist in identification of the specific nanomaterials-inherent properties that affect their release, transport, and fate in the environment, as well as their potential exposure and adverse effects on human health and ecosystems. Data and tools for evaluating relationships between inherent chemical properties of manufactured nanomaterials and their transport, transformation, and bioavailability in environmental and treatment systems are being investigated. Outcomes of the research will improve estimates of factors that affect the release of selected nanomaterials from consumer products and polymer composites, and their bioavailability, persistence, and transport in soil, water, and the atmosphere. The research will lead to better predictions of the concentrations and forms of manufactured nanomaterials to which humans and ecosystems are exposed.

EPA's nanotoxicology work will include health implications testing of several classes of commercially relevant materials. A multi-tiered testing approach will use cellular and noncellular tests, such as those in the ToxCast program, and *in vivo* toxicity testing to arrive at more efficient procedures for assessing, ranking, and predicting the toxicity of nanomaterials. These methods should also be useful in selecting more sustainable alternative materials.

Ecological effects testing will focus on freshwater, marine, and terrestrial ecosystems, and will seek to improve methods for introducing nanomaterials into test systems that represent these environments. The ecological effects work will focus on EPA-relevant nanomaterials and on identification of molecular events that initiate adverse outcome pathways at environmentally relevant concentrations and compositions. Methods for preparing test media and characterizing exposure–response relationships will be developed for the purpose of modifying testing protocols to be more accurate and efficient. Aspects such as benthic (ecological regions at the bottoms of lakes and seas) community impacts and chronic effects will be investigated.

Research using sustainable chemistry and life-cycle assessment approaches is informing a more sustainable approach to nanomaterial production. For example, in 2011 it was reported that nanoscale zero-valent iron (used for cleanup of hazardous waste sites) was produced using less hazardous chemicals relative to current commercial methods, and four other types of metal nanoparticles in addition to iron (for different commercial applications) were produced using alternative nonhazardous chemical processes.

Under its STAR program, a 2012 EPA solicitation for interdisciplinary Centers for Material Life Cycle Safety is focused on the application of a life-cycle perspective towards the development of materials, including engineered nanomaterials. The aim of the centers will be to develop methodologies and practices for materials design that apply a holistic perspective. This holistic approach, which considers all the stages of a material’s life cycle, provides an opportunity to design, develop, and produce materials that minimize, and preferably eliminate, any associated adverse environmental and human health impacts that may occur during a material’s life cycle. This approach to material design and development will direct researchers to avoid and eliminate the contributions within a material’s life cycle that most significantly influence potential hazards and thus enable ongoing materials improvements without impairment of public health or the ecosystem, in direct accordance with principles of sustainability.

FDA: The use of nanotechnology may alter safety, effectiveness, performance, and/or quality of FDA-regulated products. Nanomaterials present regulatory challenges because properties of a material relevant to the safety, effectiveness, performance, or quality of a product may change as the size of the material enters into, or varies within, the nanoscale range. For this reason, FDA is interested in additional scientific information and tools to help better detect and predict potential effects of such changes on human or animal health.

Formally joining the NNI budget crosscut for the first time in 2011, FDA will continue to conduct activities relevant to PCA 7 (environment, health, and safety) that support the following agency-wide priorities: (1) staff training and professional development, (2) laboratory and product testing, and (3) collaborative and interdisciplinary research to address nanomaterial characterization and product safety. Together, these investments support the responsible development of nanotechnology.

NIH: The NIH is addressing the research needs on nanomaterials and human health, in accordance with the 2011 NNI EHS Research Strategy. One of the long-standing research programs on nanoEHS, started in 2003 and still operational today, is the National Toxicology Program (NTP). The goal of this research program is to evaluate the toxicological properties of major nanoscale materials “classes” defined by a cross-section of composition, size, surface coatings, and physicochemical properties. These classification and characterization efforts on a given set of materials are currently being used to address how, if at all, these materials interact with biological systems of relevance to the human body.

The majority of NIEHS initiatives and extramural funding supports activities that are similar and complementary to the above research goals and to predicting human health risks in this area. In 2010, a “Nano GO” (Grand Opportunity) consortium was funded through ARRA investments to identify and develop reliable and reproducible methods to assess toxicity of nanomaterials. NIEHS also invested in the "Centers for Nanotechnology Health Implications Research" consortium in the same year. The centers are developing fundamental knowledge of the interactions between engineered nanomaterials, or nanotechnology-enabled products, and biological matrices, to assess potential health risks associated with accidental or incidental exposure. The centers have established a plan of action to assess health risks, and they are currently acquiring data sets to derive corresponding relationships for this field. NIEHS anticipates continuing its support for this area in 2013, along with potentially evaluating new opportunities to support investigations into susceptibility factors such as underlying disease, genetic factors, age, and gender in human health effects assessment. The overall NIH R&D contributions to this goal not only span across the six Nanomaterials and Human Health research needs that were identified in the 2011 NNI EHS Research Strategy document but also focus on the potential for translation of nanotherapeutics and nanotechnology-enabled diagnostics to clinical practice.

The University of Minnesota Consortium on Law and Values held a conference on 26 September 2011 to discuss analysis of and recommendations for procedures to protect human participants in research on nanomedicine products.[17] The conference and relevant research[18] were supported in part by an ARRA grant from the NIH National Human Genome Research Institute. The outcome from the conference will be the publication of a set of recommendations on human subjects governance for nanomedicine and nanotechnology research.

NIOSH: In 2013, NIOSH will follow a strategy of maintaining momentum from successful projects started in its 2010–2012 Strategic Plan[19] and increasing its investment in three key programmatic areas: (1) applying Prevention through Design to nanotechnology; (2) evaluating the effectiveness of containment and control strategies that promote safe development of nanomaterial-based products; and (3) increasing efforts to understand human exposure to nanomaterials and potential health impacts. Program themes and accomplishments are summarized below.

Evaluate potential human health hazard of exposure to engineered nanomaterials. In 2011, NIOSH scientists published breakthrough results on the biologic behavior of carbon nanotubes demonstrating pulmonary effects in laboratory animals and human epithelial cells. The potential health implications for humans are incompletely understood and will be a focus of investigation in 2012 and 2013. Key accomplishments and areas of investigation include:

- Publishing the Intelligence Bulletin on Occupational Exposure to Titanium Dioxide, in which the first-ever quantitative risk assessment and recommended exposure limit were performed and issued for a nanoscale material (2011).
- Releasing the Draft Current Intelligence bulletin on Occupational Exposure to Carbon Nanotubes and Nanofibers. The document includes a quantitative risk assessment, a recommended exposure limit, risk management recommendations for safe handling and use of carbon nanotubes/nanofibers, and research needed to close knowledge gaps (2011).
- Presenting findings on the modes of biological action at the molecular level for carbon nanotubes and other nanomaterials that have high potential for commercialization (2012), development of new lung deposition models to predict behavior of carbon nanotubes and fibers so that realistic human health risk estimates can be developed (2011, 2012), and investigation of potential genotoxic and carcinogenic effects of single-wall carbon nanotubes (2013).
- Continuing to investigate changes in biologic activity of nanomaterials brought about by changes in surface character as part of the "safe design" initiative (2012, 2013).

Develop measurement methods and conduct occupational exposure assessments. In 2011–2012, NIOSH is continuing to refine methods to measure worker exposure to airborne engineered nanomaterials of high commercial interest. Valid measurement methods are critical for accurate risk characterization and the development of risk-based control recommendations. Key accomplishments and plans include:

---

[17] www.lifesci.consortium.umn.edu/conferences/2011_nano/about

[18] www.springerlink.com/content/t3724211r2427618/

[19] DHHS/CDC/NIOSH, *Strategic Plan for NIOSH Nanotechnology Research and Guidance: Filling the Knowledge Gaps* (November 2009; www.cdc.gov/niosh/docs/2010-105/pdfs/2010-105.pdf).

- Developing, licensing, and beginning the field trials of a hand-held electrostatic precipitator for sampling nanoparticle aerosols and of a miniature-size selective particle counter (2011, 2012).
- Evaluating the correlation between particle number, surface area, mass, and size distribution from airborne results, and developing guidance for sampler selection (2011–2013).
- Generating controlled test atmosphere aerosols of select nanomaterials to evaluate a suite of measurement methods, starting with multi-wall carbon nanotubes in 2012 (2012–2013).
- Continuing to enlist private sector partners to participate in field research efforts aimed at evaluating worker exposure and developing risk management guidance. Three distinct activities will continue: initial assessments for new engineered nanomaterials, assessments for carbonaceous nanomaterials, and evaluation of containment and control strategies for nanomaterial processes (2011 into 2013).
- Continuing to integrate a life-cycle approach for following nanomaterials during initial manufacture, incorporating the nanomaterial into an intermediate product; creating a nanotechnology-enabled product, and end-of-life of the product (2012, 2013).

Risk assessment, epidemiology, and surveillance. Key accomplishments and plans include:

- Determining to what extent current human and animal exposure–response data for ultrafine particles may be used to identify potential occupational health risks of nanomaterials (2011–2013).
- Assessing the feasibility of conducting industry-wide exposure and epidemiologic studies of workers exposed to engineered nanomaterials (2012, 2013).

Engineering controls and personal protective equipment (PPE). Key accomplishments and plans include:

- Continuing a focused field research effort evaluating the effectiveness of containment and control technologies, with emphasis on nanomaterials produced in high volumes (2011–2013).
- Publishing two basic guidance documents on engineering controls and work practices: *General Research Laboratory Practices* and *General Industrial Control Strategies* (2012).

Risk management recommendations and guidance. Key accomplishments and plans include:

- Continuing to partner with private sector and public sector nanomaterials organizations to develop and disseminate effective risk-based management practices that promote and support a safe process of accelerated development and commercialization of nanomaterial-based products (2011–2013).
- Launching an initiative to develop a classification scheme for engineered nanomaterials based on chemical, physical, and biological properties. In 2012 this scheme is comparing high-volume-production nanomaterials (single-wall CNTs, multi-wall CNTs, TiO_2) to known benchmark materials to develop hazard band classifications that will allow nanomanufacturers to more accurately design risk management strategies prior to large-scale production (2011–2013).
- Publication of initial research findings on the dustiness, combustibility, flammability, and conductivity of nanomaterials. In 2012 these findings will serve as the basis for work practice and engineering guidance to eliminate or reduce the risk of fire or explosion in nanomanufacturing processes. This work is in direct support of NSI Nanomanufacturing (2012).
- Plans to issue the third revision of *Approaches to Safe Nanotechnology* (www.cdc.gov/niosh/docs/2009-125/), globally one of the most widely cited risk management guidance documents issued by a public organization (2013).

NIST: NIST is developing measurement tools to determine the physico-chemical and toxicological properties of key ENMs in relevant media (including air, water, blood, and biological tissue), and assess transformations of ENMs over time. In 2012 and 2013, NIST plans to develop transferable methods and standards to detect and characterize ENMs in nanotechnology-enabled products, sample air containing airborne ENMs, determine the concentration and properties of airborne ENMs, and assess the release of ENMs from nanotechnology-enabled products, including composites, throughout their life cycles.

NIST has recently released the world's first reference material for single-wall carbon nanotube (SWCNT) soot, the primary industrial source of SWCNTs. The new NIST material offers companies and researchers a badly needed source of uniform and well-characterized carbon nanotube soot for material comparisons as well as for chemical and toxicity analysis. In 2012 and 2013 NIST plans to release additional nanoscale reference materials, including other carbon nanotube formulations, titanium dioxide and silver nanoparticles, and nanoporous glasses, along with associated protocols for sample preparation and measurements using widely available commercial instruments.

NSF: NSF support for Goal 4 includes the NSECs on societal dimensions at Arizona State University (ASU) and University of California Santa Barbara (UCSB) and the Centers for the Environmental Implications of Nanotechnology (CEIN) at Duke University and University of California Los Angeles (UCLA). NSF's Engineering Directorate also provided supplements to the NSEC awards in 2011 and 2012 for additional studies on potential EHS implications of nanotechnology, and it plans to continue those in 2013. Examples of projects funded by NSF towards Goal 4 include the following:

- The NSF Center for Nanotechnology in Society at UCSB pursues an integrated portfolio of interdisciplinary societal research on the challenges to the successful, responsible development of nanotechnology in the United States, Europe, Asia, and other regions. One way that the center fosters that research is by its analysis of the societal meanings attributed in the global North and South to the emerging technologies at the nanoscale by diverse stakeholders, including scientists; toxicologists; policymakers and regulators; environment, health, and safety personnel; the nanomaterials industry; public and public interest groups; and journalists. The center contributes to responsible development of these technologies by engaging with those key stakeholders on pertinent societal issues, including those having to do with ethics, law, policy, risk perception, and national security.
- Two long-term research goals of the NSF Center for Nanotechnology in Society at ASU are to demonstrate and refine the ability to cultivate reflexivity and build the capacity for anticipatory governance of emerging nanotechnologies. By "reflexivity" is meant a capacity for social learning by individuals, groups, institutions, and publics about nanotechnologies. Building on that capacity serves to expand the domain of participants in, and provide better information about, available choices for decision-making about nanotechnologies. By "anticipatory governance" is meant a broad-based capacity that extends throughout society that can collect, analyze, synthesize, and interpret a wide range of information to manage emerging knowledge-based technologies.

USDA/FS: Forest-based materials such as nanostructured cellulose are renewable. Responsible development of nanocellulose will require that the origins of these materials can be traced to responsibly managed forests, that they are produced in a responsible way, and that they are formulated into products that also are manufactured in a responsible way. To support the responsible development of these forest-based materials, FS scientists have collaborated with the Consortium for Research on Renewable Industrial Materials in life-cycle analysis of renewable materials where portions of the consortium's life-cycle data can be used to understand the environmental benefits of nanocellulose. USDA/FS scientists are also exploring the benefits of using Environmental Product Declarations (EPD) according to ISO 14025 to describe the environmental attributes of renewable forest-based products. Results from the EPD forest products studies can also be used to describe the environmental attributes of nanocellulose and nanocellulose-based products.

USDA/NIFA: NIFA continues to support Goal 4 in the development of methods for 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 that may attach onto and be absorbed into fresh food crops and nuts, and to 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 transport fates of nanomaterials by agricultural crops—including potential impacts on coexisting contaminants—and explore potential risks to humans from exposure through food chain contamination.

USGS: United States Geological Survey projects investigate bioavailability of nanomaterials to aquatic organisms, metal and carbon-based nanoparticle toxicity on flora and fauna, and use of bacteria as a novel means to manufacture nanoparticles. In addition, the USGS is developing tools that allow monitoring of nanomaterials in the environment. These research areas are further described below:

- *Bioavailability and toxicity.* This research focuses on the assessment of bioavailability and toxicity of well-characterized engineered silver and copper oxide and carbon nanoparticles to flora and fauna.
- *Bacterial formation of nanoscale minerals.* This research focuses on exploring the potential of bacteria to produce arsenic sulfide and antimony sulfide nanoscale minerals with possible applications in photonics and photovoltaics. The research includes investigation of antimony respiration by bacteria, using field and laboratory components, to demonstrate the role of bacteria in this process. These efforts complement research on bacterial formation of selenium and tellurium nanomaterials. Such "green" approaches to nanomaterial formation can be more efficient and environmentally friendly than other approaches.
- *Interactions of dissolved organic matter (DOM) with metal sulfide nanoparticles formed* in situ*.* This research addresses interactions between DOM and nanoscale mercuric sulfide, zinc sulfide, and copper sulfide. The primary focus is on mercuric sulfide–DOM interactions, including at low mercury concentrations. This effort to better define the actual geochemistry of these interactions is being paired with studies to assess the influence of these interactions on methylation of mercury by sulfate-reducing bacteria. The effect of DOM is to mediate exposure to these metal species.

Coordinated Activities with other Agencies and Institutions Contributing to Goal 4

CPSC, other NNI agencies, international organizations: The CPSC is collaborating with other Federal agencies, as part of the NNI, to support the development of exposure and risk assessments of nanomaterials. CPSC signed the interagency agreements outlined below to conduct exposure studies that will be used to develop methods needed to meet identified data gaps and adequately address potential hazards and promote the responsible development of products containing nanomaterials:

- In 2011, CPSC signed an interagency agreement with EPA to support a comprehensive multinational study in collaboration with agencies in the United Kingdom that is investigating the potential human exposures to nanomaterials resulting from the use of consumer products, as well as from contact with selected nanomaterials from environmental sources. The study will quantify the potential health risks of these exposures.
- NSF and EPA have co-funded the development of the two Centers for Environmental Implications of Nanotechnology at Duke University and UCLA. These university-based centers focus on the environmental and public health implications of nanotechnology and concentrate on the fate and transport of nanomaterials in the environment and exposures to various organisms. They also seek to

understand human exposures to nanomaterials, including those released from consumer products. CPSC staff members support investigations at these centers, which use innovative techniques to characterize nanomaterials in selected consumer products and quantify exposures to humans. The project will also synthesize data to develop a risk assessment framework for nanomaterials used in consumer products.

- Through a collaborative effort by NIOSH, EPA, and CPSC, NIOSH and EPA have conducted product testing using scientifically credible protocols. This testing has evaluated the potential exposure to nano-silver that could result from use of nanomaterial-containing consumer products. NIOSH staff continues to develop and refine methods to quantify release of nanoparticles from aerosol products.
- In 2011, NIST and the CPSC signed multiyear interagency agreements to evaluate the release of ENMs from nanotechnology-enabled products and characterize airborne nanoparticles.

CPSC staff will continue investments in these studies to address identified gaps in knowledge and methods needed to support informed decision-making regarding the safety of products containing nanomaterials.

CPSC, EPA, NIOSH, NIST, OSHA, nonprofit groups, industry, international organizations: Five NNI agencies are collaborating with the Consumers Union, the AFL-CIO, the Dow Chemical Company, Evonik Degussa Corporation, Health Canada, Environment Canada, and other groups through the ILSI Research Foundation's Nanorelease Project.[20] This project seeks to develop methods for measuring the release of engineered nanomaterials such as carbon nanotubes from commercially relevant consumer materials that incorporate these engineered nanomaterials in order to better foster the safe development of nanomaterials. In May 2011, experts from these agencies and organizations met to refine project objectives; select the material that will be used to develop methods to measure release of multi-wall carbon nanotubes (MWCNTs) embedded in polymer matrices; and initiate the development of a state-of-the-science document and work plan for "Phase 3" methods testing, development, and proof of utility for articles in commerce. In 2013, this project will finalize methodology for testing products and will start an interlaboratory round robin testing program.

DOD, EPA, NNI agencies, other U.S. Government agencies: As co-chair of DOD's Nano EHS Work Group, Environmental Readiness and Safety staff members from the Office of the Deputy Under Secretary of Defense for Installations and Environment participate in efforts to determine potential and future roles of nanomaterials in the following areas:

- *Green chemistry (GC) research*. The NSTC Committee on Environment, Natural Resources, and Sustainability, Subcommittee on Toxics and Risks, is developing a GC research framework and is identifying opportunities for agency collaboration and resource leveraging. Research into safer and greener products and processes due to advances in nanotechnology can be expected to play a key role.
- *Sustainable manufacturing (SM)*. A new Interagency Network of Enterprise Assistance Providers (Subcommittee on Sustainable Manufacturing) will begin work in 2012. Although nanotechnology is not its own industry sector, advances in nanotechnology may contribute to a number of new sustainability tools developed for manufacturers, especially small- and medium-size businesses.

DOD, other NNI agencies, other nations: Examples of Department of Defense coordinated activities related to Goal 4 include the following:

- The Air Force has reached out to the international research community and multiple countries to communicate about nanomaterials toxicity and risk analysis. For example, the Air Force has project

[20] www.ilsi.org/ResearchFoundation/Pages/NanoRelease1.aspx

agreements signed with India and Sweden's defense ministries and laboratories to research nanotoxicity. It is collaborating with EPA to evaluate the toxicity of green nanomaterials and to characterize the hazards associated with defense nanotechnologies. Through this collaboration the DOD has focused on using nano-silver synthesized by green methods. AFRL is coordinating with NIOSH in the assessment of laboratory personnel who might be exposed to nanoparticles. Air quality studies have been performed in several laboratories to determine the potential for laboratory personnel to be exposed to engineered carbon-based nanomaterials or metal-based nanomaterials while conducting research. These assessments have identified nanomaterials that can become airborne and result in potential worker exposure and have led to the development of practices to minimize exposure. AFRL has established a collaboration with the National Center for Toxicological Research (NCTR) at FDA. While the majority of the research focus at the DOD level has been performed using *in vitro* models, the need to transition to *in vivo* models has also been recognized. Therefore, the Air Force has developed a good working relationship with NCTR/FDA to perform more extensive *in vivo* studies using the data from the *in vitro* evaluations.

- The Army is collaborating with the EPA to apply the Comprehensive Environmental Assessment (CEA) process to evaluate potential environmental hazards associated with new defense nanotechnologies. The CEA is both a framework for making comparisons and a process that guides project risk managers who monitor risk/benefit tradeoffs of nanotechnology products and practices.

EPA, other NNI agencies, OECD, EU: EPA researchers and regulators work with other U.S. agencies and departments and with other nations in the international testing program being conducted under the auspices of the OECD Working Party on Manufactured Nanomaterials (WPMN). The WPMN has completed testing on numerous nanomaterials using OECD protocols, and it will continue its testing program and other risk assessment and green nanomaterials collaborations.

EPA has also partnered with several agencies and departments (NNCO, NIOSH, CPSC, OSHA, DOS) and the private sector (American Association for the Advancement of Science, Bilat USA, industry) through the NNI to engage the EU in other partnering efforts (see us-eu.org). Following a successful workshop with the EU in 2011, partners in the U.S.–EU collaboration will establish communities of research around specific nanomaterial EHS research areas in the 2012 to 2013 timeframe.

EPA, NSF, USDA/NIFA, CPSC, United Kingdom, OECD: These NNI agencies collaborate in both funding and conducting research as well as issuing joint grant solicitations with other governments. Specifically, EPA's STAR Program has issued joint solicitations with NSF and USDA. In 2010, EPA, CPSC, and the United Kingdom awarded three joint U.S.–UK consortia proposals. Three U.S. teams and three UK teams received awards supporting the three consortia research proposals.

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

NIH/NIEHS, NIOSH: NIEHS is collaborating with NIOSH through an interagency agreement on several projects that evaluate possible workplace exposures. This may include exposure to specifically engineered nanoscale materials or incidentally generated nanoscale particles.

NIH (NCI, NIBIB, NIEHS), NNI participating agencies: Since September 2010, NCI, NIBIB, and NIEHS have developed the Nanomaterial Registry. The "NanoRegistry" supports the nanomaterial community by providing curated information about the physico-chemical characteristics as well as the environmental and biological interactions of well-characterized nanomaterials. The NanoRegistry builds its repository of curated nanomaterial information by extracting data from a broad collection of publicly available nanomaterial resources from caNanoLab and other sources. It also promotes the use of a well-defined Minimal Information About Nanomaterials (MIAN) framework and common nanomaterial standards.

NIOSH, international organizations: Key NIOSH international accomplishments and plans include:

- Continuing its leadership role in ISO Technical Committee 229 in activities such as developing and disseminating guidance on nanomaterials exposure measurement and control; guidance for developing exposure limits; application of control banding to nanomaterials; and development of an epidemiologic framework to evaluate potential health effects among nanomaterial workers (2011–2013).
- Continuing its participation in key OECD projects, including the Nanomaterial Safety Testing Program (SWCNT, MWCNT, nano-silver); NIOSH is leading the project on exposure mitigation (2011–2013).
- Global dissemination of NIOSH guidance documents: NIOSH nanotechnology risk management documents have been translated into Japanese, Italian, Portuguese, Spanish, Chinese, and Ukrainian (2011–2013).

NIOSH, other NNI agencies, academia, industry: In 2011–2013 NIOSH will continue existing collaborations or create new formal working relationships with key NNI agencies and external collaborators such as universities and private nanomaterial companies to develop and disseminate effective EHS risk management methods to support responsible development of nanomaterial manufacturing processes. Many of these NIOSH collaborations are in direct support of NSI Nanomanufacturing. They include:

- Continuing to explore opportunities under an interagency agreement with OSHA to investigate potential worker exposure in businesses that manufacture or use nanomaterials, to evaluate control technologies and risk management methods, and to jointly develop risk management guidance for small businesses. NIOSH will continue to 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 (2011–2013).
- Renewal in 2012 of an Interagency Agreement with the NIEHS National Toxicology Program to conduct field research site visits to nanomanufacturing facilities and investigate potential worker exposure to nanomaterials that have not been previously evaluated. NIOSH also has entered into a new agreement with NTP to support a focused effort for carbonaceous nanomaterials: CNTs, nanofibers, and graphene. In four years, NIOSH staff members have visited 30 sites and evaluated over ten different nanomaterials in processes ranging from basic research laboratories to high-volume production. Following every NIOSH site visit, the host organization is issued a comprehensive report of findings, measurements, observations, and recommendations, all in support of developing good risk management practices that promote safe accelerated innovation and speed to market (2011–2013).
- Maintaining two separate interagency agreements with CPSC: (1) Characterizing the aerosol released by a nanoscale TiO_2-based spray bathroom disinfectant and conducting animal toxicology testing of the product; in 2012 and 2013, CPSC will use NIOSH results to gain a better understanding of user exposure and evaluate possible health risk. (2) Determining bioavailability of nano-silver from various treated surfaces and products. NIOSH is reapplying its expertise in these two areas because of the commercial applications possible (2011–2013).
- Continuing to operate under a framework memorandum with DOD 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 banding for some pilot projects, and demonstrate the effectiveness of using PtD principles on new nanomaterial processes (2011–2013).
- Continuing collaborations with EPA in the Spray-Applied Nanomaterials work group and continuing to provide information on NIOSH's workplace field efforts in order to provide EPA with information on current practices being used by the nanomaterials business community (2011–2013).

- Providing a test bed for deployment of PtD in the nanoelectronics sector under a memorandum of understanding (MOU) with the University at Albany College of Nanoscale Science and Engineering (CNSE). There will also be an increased investment in demonstrating effective containment and control systems needed to accelerate innovation and commercialization of nanomaterial-enabled products while providing worker and environmental protection. A dual-themed workshop to be held in late 2012 at CNSE will focus on the application of PtD principles to the design of new nanomaterials and to the design of nanomaterial production facilities, processes, tools, and tasks (2011–2013).
- Continuing an MOU with the multi-university Center for High-Rate Nanomanufacturing. Key program activities within this MOU include collaboration on EHS practices with University of Massachusetts Lowell to develop risk management practices for nanomanufacturing, and partnering with Northeastern University on the value of incorporating PtD principles into life cycle management of nanomaterials (2011–2013).
- Creating collaboration opportunities with the SEMATECH semiconductor manufacturing consortium, through the MOU with CNSE, for development of good risk management practices for incorporation of nanomaterials in semiconductor fabrication and next-generation, nanomaterial-based photovoltaic manufacturing. In 2012 and 2013 NIOSH will work with SEMATECH, Semiconductor Equipment and Materials International, and the International SEMATECH Manufacturing Initiative to introduce PtD principles into the manufacture and use of nanomaterials in the semiconductor industry. The collaboration with CNSE creates similar opportunities in solar energy and photovoltaic research, development, and production (2012–2013).
- Continuing to collaborate with the Center for Multifunctional Polymer Nanomaterials and Devices. Work with 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 startup businesses (2012 and 2013).
- Supporting the development and deployment of the GoodNanoGuide (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. In 2013, NIOSH will integrate activities in nanoinformatics with the GoodNanoGuide and will also actively seek a new host for the system (2012–2013).
- Continuing to expand support and leadership activities in nanotechnology safety and health in the World Health Organization, and direct participation in projects within the EU framework, such as NanoImpactNet, NanEx, and NanoDevice (2013).
- Continuing to partner on broad scientific community development of the Nanoinformatics 2020 Roadmap, which advances mechanisms for the nanotechnology communities to collect, validate, store, share, mine, analyze, model, and apply nanotechnology information.

NIST, EPA: In 2011, NIST signed an interagency agreement with EPA to sample airborne ENMs and investigate changes in the ENMs over time.

NIST, FDA, EPA, NIOSH, CPSC: These agencies support investments in the development of benchmark data, measurement methods, and prototype reference materials for nano-silver for EHS assessments of products containing this nanomaterial.

NSF, EPA, USDA/NIFA, EC: These NNI agencies collaborate with each other as well as internationally (e.g., with the European Commission) in funding and coordinating research related to Goal 4 by supporting workshops and joint research and education programs. NSF and EPA continue to 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 two NSF-sponsored Centers for Nanotechnology in Society.

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

USDA/NIFA, IFT, NNCO: USDA/NIFA and the Institute of Food Technologists will co-sponsor a symposium titled "Safety Evaluation of Nanodelivery Systems in Foods" that will be held as part of the Scientific Program of the IFT's Annual Meeting & Food Expo in Las Vegas, NV, 25–28 June 2012. The program will feature three technical presentations of the research projects funded by NIFA on safety assessment of nanoparticles in foods.

USDA/NIFA, NSF: USDA/NIFA is organizing a mini-symposium on Education, Outreach, Public Perception and Acceptance of Nanotechnology Applications in Food and Agriculture, in conjunction with its annual grantees' conference to be held 2–4 February 2012 in Orlando, FL. This includes a site visit to the interactive nanotechnology exhibition (Nanooze) funded primarily by NSF with supplemental support from NIFA.

USGS, CPSC, EPA, academia, United Kingdom: A USGS investigator is working closely with grantees from the University of California Davis and the University of Birmingham (UK) who are supported under the joint EPA/CPSC/UK EHS research solicitation.

External Reviews of the NNI

The 21st Century Nanotechnology R&D Act 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). Input from NRC and NNAP reviews has been incorporated into the 2011 NNI Strategic Plan and into the 2011 NNI Strategy for Environmental, Health, and Safety Research.

Summary of NNI Progress in Addressing 2010 PCAST/NNAP Recommendations

The most recent review of the NNI by the President's Council of Advisors on Science and Technology (PCAST), in its role as the National Nanotechnology Advisory Panel, was released in March 2010.[21] The following is a list of recommendations in the Executive Report of the March 2010 PCAST/NNAP report. General subjects of these recommendations or direct quotes from these recommendations are included below in italics, followed by summaries of the NNI progress towards implementing each of them to date, in normal text. These are organized under three headings: (1) actions completed, (2) actions initiated but not fully implemented, and (3) recommendations considered, but actions by the NNI specifically are unlikely or not needed.

[21] *Report to the President and Congress on the Third Assessment of the National Nanotechnology Initiative* (Executive Office of the President, Washington, DC, 2010; whitehouse.gov/sites/default/files/microsites/ostp/pcast-nni-report.pdf).

Actions completed

- *Strategic planning.*
  - The NNI Strategic Plan was released in February 2011 and identifies three- to five-year objectives for each of the NNI goals, including specific objectives addressing societal impacts.
  - The NNI EHS Research Strategy, released in October 2011, targets science to protect human health and the environment and to support product development. It contains clear principles to guide identification of plausible risks.
- *Coordination of nanotechnology standards and EHS research across the Government.*
  - The OSTP designated individuals within the NNCO to lead interagency coordination efforts in EHS research (Deputy Director Sally Tinkle) and standards development (then-Director Clayton Teague).

Actions in progress

- *Nanotechnology Signature Initiatives: Milestones and public/private partnerships.*
  - Interagency task forces for the three Nanotechnology Signature Initiatives (NSIs) that were announced in the 2011 budget are currently developing coordination plans that include milestones. Development of new topics is underway, with the likelihood that at least two will be added within the next year.
  - Several NNI agencies are developing new public–private partnerships, and the NSI task forces are exploring ways to incorporate them into the NSIs.
- *Developing metrics for the economic impact of nanotechnology and the NNI.*
  - NNCO has discussed nanotechnology economic metrics with Department of Commerce analysts, is providing support for the Symposium on Economic Value of Nanotechnology (scheduled for March 2012 in Washington, DC), and has requested metrics to assess the success of nanotechnology as part of the current triennial NRC review of the NNI.
- *Nanomanufacturing and commercialization: Double the NNI investment in nanomanufacturing.*
  - Key NNI agencies are on track to maintain their investment in fundamental research while doubling their nanomanufacturing investments over a five-year period.
- *Invest in education: Consider an evaluation of the outcomes of the overall investment in NNI education.*
  - NNI agencies are contributing to nanotechnology curricula for grade school through postdoctoral training; NSF is considering an external study to evaluate the NNI educational investment.
- *Job creation: Create new jobs in the United States, including coordinating with State efforts; economic impact should be an explicit metric in the second decade of the NNI.*
  - The NSET Nanomanufacturing, Industry Liaison, and Innovation Working Group, in conjunction with the NNCO Industry and State Liaison, is developing a work plan that includes job creation and increased outreach to states and industry.
- *Moving nanotechnology to market: Clarify the development pathway…accelerate technology transfer to the marketplace.*
  - Key NNI agencies are employing well-established mechanisms, such as the SBIR and STTR programs, and are developing several new programs to accelerate technology transfer to the marketplace and to clarify regulatory pathways.

- *Information resources: [The] NEHI working group should develop information resources on crosscutting nanotechnology EHS issues…*
    - o The NSET Nanotechnology Environment and Health Implications (NEHI) Working Group has established a framework to receive from stakeholders and provide information on crosscutting nanoEHS issues. Plans include external speakers at monthly meetings, public workshops, and webinars and other social media.

Recommendations considered but actions unlikely or not needed

- *Require each agency in the NNI to have senior representatives with decision-making authority participate in coordination activities of the NNI.*
    - o Representation on the NSET Subcommittee is determined within each agency.
- *Strengthen the NNCO to enhance its ability to act as the coordinating entity for the NNI.*
    - o The NSET Subcommittee serves as the coordinating entity for the NNI, and the NNCO serves as the administrative support to NSET.
- *Dedicate 0.3 percent of NNI funding to the NNCO to ensure the appropriate staffing and budget to effectively develop, monitor, and assess NNI programs.*
    - o The NSET Subcommittee discussed, but did not support, the recommendation to fix NNCO funding at a specific percentage of the NNI investment; current funding for NNCO activities is based on programmatic needs as proposed each year by NNCO and vetted by the NSET Subcommittee's Budget Steering Group.
- *Congress and the Administration need to take steps to retain scientific and engineering talent trained in the United States by developing a program to provide U.S. Permanent Resident Cards for foreign individuals who receive an advanced degree in science or engineering at an accredited institution in the United States and for whom proof of permanent employment in that scientific or engineering discipline exists.*
    - o The NNI agencies agree that steps need to be taken to retain scientific and engineering talent in the United States but do not endorse specific approaches at this time.
- *Organizational changes: The NSET Subcommittee and OSTP should foster administrative changes and communications mechanisms that will enable the NNI to better embrace the EHS issues associated with nanotechnology research, development, and commercialization.*
    - o NSET/NEHI coordinates nanoEHS research, and the Emerging Technology Interagency Policy Committee coordinates nanoEHS policy issues.

Other Ongoing Reviews

A new triennial NRC review of the NNI was initiated in the fall of 2011, with a final report anticipated in spring 2013.

In addition, the NRC issued a report in late January of 2012 entitled *A Research Strategy for Environmental, Health, and Safety Aspects of Engineered Nanomaterials*, commissioned by the Environmental Protection Agency at the request of Congress. The NRC committee was charged with developing and monitoring the implementation of an integrated U.S. research strategy to address the EHS aspects of engineered nanomaterials. This first report outlines a research strategy, and a follow-up report (18 months later) will evaluate the implementation of the suggested strategy. The NNI agencies are just beginning to assess the first report and consider how its recommendations may be applied to the NNI EHS research program.

Appendix A. Glossary

Act Public Law 108-153, the 21st Century Nanotechnology Research and Development Act

AFRI Agriculture and Food Research Initiative (USDA/NIFA)

AFRL Air Force Research Laboratory

Agencies Departments, agencies, and commissions within the Executive Branch of U.S. Federal Government

AMO Advanced Manufacturing Office of DOE/EERE (formerly the Industrial Technologies Program)

AMP Advanced Manufacturing Partnership

AMRDEC Aviation and Missile Research Development and Engineering Center (U.S. Army)

ARO Army Research Office (DOD)

ARS Agricultural Research Service (USDA)

ARPA-E Advanced Research Projects Agency for Energy (DOE)

ARRA American Recovery and Reinvestment Act of 2009

BIS Bureau of Industry and Security (DOC)

CCI Center for Chemical Innovation (NSF)

CDC Centers for Disease Control and Prevention (DHHS)

CEIN Centers for Environmental Implications of Nanotechnology

NCNR NIST Center for Neutron Research

CNC cellulose nanocrystals

CNF cellulose nanofiber

CNSE College of Nanoscale Science and Engineering (University at Albany, State University of New York)

CNST Center for Nanoscale Science and Technology (DOC/NIST)

CNT carbon nanotube

CNTC Cancer Nanotechnology Training Center (DHHS/NIH/NCI)

CoT Committee on Technology of the NSTC

CPSC Consumer Product Safety Commission

CWA chemical warfare agent

DARPA Defense Advanced Research Projects Agency

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

DOM dissolved organic matter

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 environment[al], health, and safety

ENM engineered nanomaterial

EPA Environmental Protection Agency

ERC Engineering Research Centers (NSF)

EU European Union

FDA Food and Drug Administration (DHHS)

FHWA Federal Highway Administration (DOT)

FS Forest Service (USDA)

GC green chemistry

IC Intelligence Community

IDE investigational device exemption

ILSI International Life Science Institute

IND investigational new drug

ISO International Organization for Standardization

ITP Industrial Technologies Program (DOE/EERE)

MEMS microelectromechanical systems

MOF metal-organic framework

MOU memorandum of understanding

MRSEC Materials Research Science and Engineering Centers (NSF)

MWCNT multi-wall carbon nanotube

nanoEHS nanotechnology environment, health, and safety [research]

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
NERC	Nanosystems Engineering Research Centers (NSF)
NHGRI	National Human Genome Research Institute (DHHS/NIH)
NIBIB	National Institute of Biomedical Imaging and Bioengineering (DHHS/NIH)
NIDCR	National Institute of Dental and Craniofacial Research (DHHS/NIH)
NIEHS	National Institute of Environmental Health Sciences (DHHS/NIH)
NIFA	National Institute of Food and Agriculture (USDA)
NIH	National Institutes of Health (DHHS)
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
NPL	nanoparticle lubricant
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
NSI	Nanotechnology Signature Initiative
NSF	National Science Foundation
NSRC	Nanoscale Science Research Centers (DOE)
NSTC	National Science and Technology Council
NTP	National Toxicology Program (DHHS/multiagency)
NUE	Nanotechnology Undergraduate Program (in Engineering) (NSF)
OECD	Organisation for Economic Co-operation and Development
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
PEN	Program(s) of Excellence in Nanotechnology (DHHS/NIH)
POM	polyoxometalate
PtD	Prevention through Design
RF	radio frequency
SBIR	Small Business Innovation Research Program
SI	International System of Units (Le Système International d'Unités)
siRNA	small-interfering ribonucleic acid
SM	sustainable manufacturing
STAR	Science To Achieve Results (EPA)
STRF	Space Technology Research Fellowship (NASA)
STTR	Small Business Technology Transfer Research Program
SWCNT	single-wall carbon nanotube
TAPPI	Technical Association of the Pulp and Paper Industry
UK	United Kingdom (Great Britain)
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)
WPMN	Working Party on Manufactured Nanomaterials (under the Chemicals Committee of the OECD)
WPN	Working Party on Nanotechnology (OECD)

Appendix B. Contacts List

OSTP

Dr. Altaf H. Carim
Assistant Director for Nanotechnology
Office of Science and Technology Policy
Executive Office of the President
Washington, DC 20502
T: 202-456-7825
acarim@ostp.eop.gov

OMB

Ms. Celinda Marsh
Office of Management and Budget
Executive Office of the President
725 17th St., N.W.
Washington, DC 20503
T: 202-395-5835
Celinda_A._Marsh@omb.eop.gov

NNCO

Dr. Sally Tinkle
Deputy Director / Acting Director, and Coordinator for Environmental, Health & 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
Leader, Chemical Hazards Program
Office of Hazard Identification & 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

Mr. 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

Ms. Kelly Gardner
Export Policy Advisor
U.S. Department of Commerce
Bureau of Industry and Security
Office of National Security and Technology Transfer Controls
14th St. & Constitution Ave., N.W.
Rm. 2600
Washington, DC 20230
T: 202-482-0102; F: 202-482-3345
Kelly.Gardner@bis.doc.gov

DOD

Dr. Lewis Sloter
Associate Director, Materials & Structures
Office of the Assistant Secretary of Defense for Research and Engineering
AT&L (ASDR&E)
4800 Mark Center Dr.
Alexandria VA 22350-3600
T: 571-372-6511; F: 571-372-6500
Lewis.Sloter@osd.mil

Dr. Khershed Cooper
Program Officer
Office of Naval Research, ManTech
Materials Science & Technology Division, Code 6324
Naval Research Laboratory
555 Overlook Ave. SW
Washington, DC 20375-5343
T: 202-767-0181; F: 202-767-2623
khershed.cooper@nrl.navy.mil

Dr. Akbar S. Khan
Senior Microbiologist & S&T Manager
Basic & Supporting Research Div.
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

Dr. David M. Stepp
Chief, Materials Science Division
Army Research Office
AMSRD-ROE-M (Materials Science Division)
P.O. Box 12211
Research Triangle Park, NC 27709
T: 919-549-4329; F: 919-549-4399
david.m.stepp.civ@mail.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
Advanced Manufacturing Office
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

DOEd

Mr. Peirce Hammond
Senior Advisor for Special Initiatives
U.S. Department of Education
Office of Vocational and Adult Education
Room 11-106 Potomac Center Plaza
400 Maryland Avenue, SW
Washington, DC 20202-7100
T: 202-245-6056
Peirce.Hammond@ed.gov

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

Mr. 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

Mr. 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

DOT

Mr. 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

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

Dr. Carlos Peña
Director, Emerging Technology Programs
Office of the Commissioner
FDA
10903 New Hampshire Avenue
WO Bldg 32 Room 4264
Silver Spring, MD 20993
T: 301-796-8521; F: 301-847-8617
carlos.pena@fda.hhs.gov

NASA

Dr. Michael A. Meador
Nanotechnology Project Manager, Game Changing Technologies
National Aeronautics and Space Administration
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
Office of the Chief Technologist
National Aeronautics and Space Administration
NASA Headquarters, Rm. 5Q29
Washington DC 20546-0001
T: 202-358-4518; F: 202-358-3223
minoo.n.dastoor@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. Lori Henderson
Program Director
Clinical Trials Branch/Cancer Imaging Program
Division of Cancer Treatment and Diagnosis
National Cancer Institute
6130 Executive Blvd.
Rockville, MD 20892
T: 301-451-6449; F: 301-480-3507
hendersonlori@mail.nih.gov

NIH/OD

Dr. Nancy E. Miller
Senior Science Policy Analyst
Office of Science Policy & 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
Nancy.Miller1@nih.gov

NIH/FIC

Mr. 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
herrfurg@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@ncifcrf.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/NIBIB

Dr. Steven Zullo
Gene and Drug Delivery, Nanotechnology Program Director
NIBIB, Division of Discovery Science and Technology
Democracy II-227
6707 Democracy Blvd
Bethesda, MD 20892
T: 301-451-4774; F: 301-480-1614
zullo@helix.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

Mr. 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 Coordination 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

Dr. Ajit Jillavenkatesa
Standards Coordination Office
National Institute of Standards and Technology
100 Bureau Drive, Stop 2100
Gaithersburg, MD 20899-2100
T: 301-975-8519; F: 301-975-4715
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
debra.kaiser@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
lloyd.whitman@nist.gov

NRC

Mr. 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. Thomas Rieker
Program Director, Division of Materials Research
National Science Foundation
Directorate for Mathematical and Physical Sciences
4201 Wilson Blvd., Suite 1065
Arlington, VA 22230
T: (703) 292-4914
F: (703) 292-9035
trieker@nsf.gov

Dr. Grace J. Wang
Program Manager, SBIR/STTR
Office of Industrial Innovation
National Science Foundation
4201 Wilson Blvd., Rm. 590
Arlington, VA 22230
T: 703-292-2214; F: 703-292-9057
jiwang@nsf.gov

USDA/ARS

Dr. Robert Fireovid, National Program Leader - Biobased Products and Biorefining
USDA Agricultural Research Service
5601 Sunnyside Avenue
GWCC 4-2264
Beltsville, MD 20705-5140
T: 301-504-4774; F: 301-504-6231
Robert.Fireovid@ars.usda.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
HCHEN@nifa.usda.gov

USDA/FS

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. Cynthia West
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
cdwest@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

USGS

Dr. Sarah Gerould
Staff Scientist, Ecosystems Mission Area
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

Ms. 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

Mr. David R. Gerk
Patent Attorney
Office of Policy and External Affairs
Patent and Trademark Office
P.O. Box 1450
Alexandria, VA 22313
T: 571-272-9300; F: 571-273-0085
david.gerk@uspto.gov

Mr. Bruce Kisliuk
Assistant Deputy Commissioner for Patent Operations
Patent and Trademark Office
P.O. Box 1450
Alexandria, VA 22313
T: 571-272-8800
Bruce.Kisliuk@uspto.gov

Additional NNCO Staff Contacts

Ms. Marlowe Epstein
Communications Director
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

Mr. 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

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