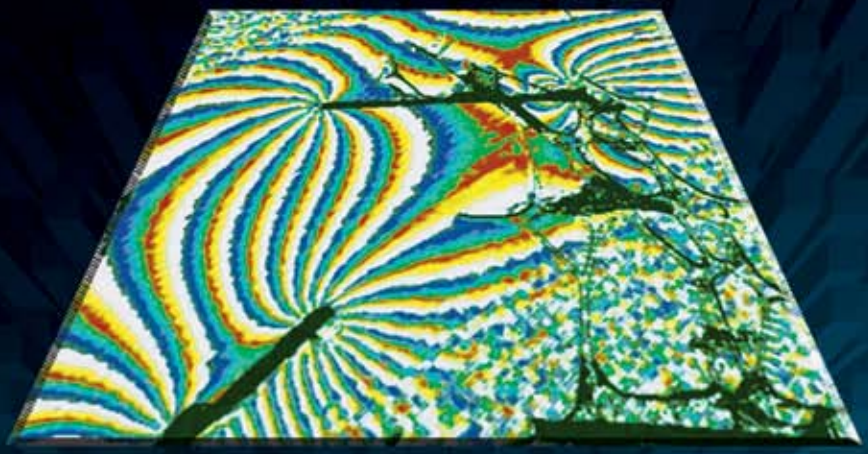
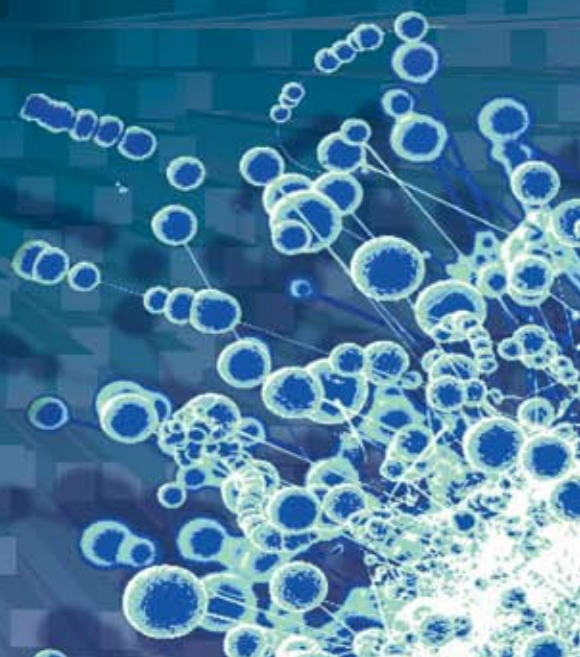
THE NATIONAL NANOTECHNOLOGY INITIATIVE

Research and Development Leading to a Revolution in Technology and Industry

Supplement to the President's FY 2007 Budget





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About the National Science and Technology Council

The National Science and Technology Council (NSTC) was established by Executive Order on November 23, 1993. The Cabinet-level council is the principal means by which the President coordinates science, space, and technology policies across the Federal Government. NSTC coordinates the diverse parts of the Federal research and development enterprise. An important objective of the NSTC is the establishment of clear national goals for Federal science and technology investments in areas ranging from nanotechnology and health research to improving transportation systems and strengthening fundamental research. The Council prepares research and development strategies that are coordinated across Federal agencies to form a comprehensive investment package aimed at accomplishing multiple national goals. Please call the NSTC Executive Secretariat at 202-456-6101 to obtain additional information regarding the NSTC, or visit the NSTC website at www.ostp.gov/nstc/.

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The Office of Science and Technology Policy (OSTP) was established by the National Science and Technology Policy, Organization, and Priorities Act of 1976. OSTP's responsibilities include advising the President in policy formulation and budget development on all questions in which science and technology (S&T) are important elements; articulating the President's S&T policies and programs; and fostering strong partnerships among Federal, State, and local governments, and the scientific communities in industry and academia. The Director of OSTP also serves as Science Advisor to the President and manages the NSTC for the President. Please call 202-456-7116 to obtain additional information regarding OSTP, or visit the OSTP website at www.ostp.gov/.

About this document

This document is a supplement to the President's 2007 Budget Request submitted to Congress on February 6, 2006. It gives a description of the activities underway in 2006 and planned for 2007 by the Federal Government agencies participating in the National Nanotechnology Initiative (NNI), primarily from a programmatic and budgetary perspective. It is based on the NNI Strategic Plan released in December 2004 and reports estimated investments for 2006 and requested investments for 2007 by program component area (PCA), as called for under the provisions of the 21st Century Nanotechnology Research and Development Act (Public Law 108-153). Please call 703-292-8626 to obtain additional information regarding the NNI, or visit the NNI website at www.nano.gov/.

About the cover

Central image: Phase contour map of piezoelectric lead barium zirconate (PBZ) nanotubes and surrounding electric fields obtained by electron holography, courtesy of Bernhard Frost and David Joy, University of Tennessee, Knoxville, and Oak Ridge National Laboratory. Performed in a specially-equipped transmission electron microscope, electron holography exploits the wave-like characteristics of electrons to map the fields in and around nanomaterials. It provides valuable information on the nanometer scale about materials such as PBZ, which is being investigated for use in a new generation of small sensors and precise actuators.

Background image: Germanium beads on a zinc oxide nanowire, courtesy of Zhengwei Pan, Chemical Sciences Division and Center for Nanophase Materials Sciences, Oak Ridge National Laboratory.

The Center for Nanophase Materials Science is the first of five Nanoscale Science Research Centers funded by the Department of Energy to go into full operation (in 2006) and is a key part of the National Nanotechnology Initiative's investment in research infrastructure.

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The National Nanotechnology Initiative

Research and Development Leading to a Revolution in Technology and Industry

Supplement to the President's 2007 Budget

July 2006

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

Report prepared by

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

July 17, 2006

MEMBERS OF CONGRESS:

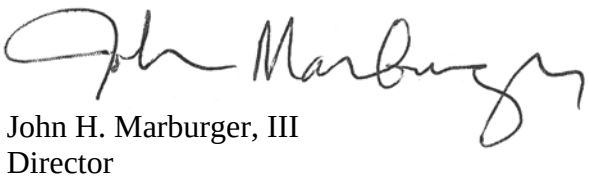
I am pleased to forward with this letter the annual report on the multi-agency National Nanotechnology Initiative (NNI). This Supplement to the President's Budget for Fiscal Year 2007 describes the programs and activities taking place across all 25 of the agencies that are participating today in the NNI. Nanotechnology research and development (R&D) is inherently multidisciplinary and the rate of progress depends on the strong interagency coordination that is taking place, as described in this report, to leverage expertise throughout the Federal Government.

The NNI is now in its sixth year, and the proposed budget for Fiscal Year (FY) 2007 is nearly triple the amount spent at the outset of the program in FY 2001. This investment is distributed across 13 agencies, supporting missions that range from addressing our energy needs and developing technologies for early diagnosis of disease to enhancing homeland and national security. Funding under the NNI supports a broad range of R&D, along with a geographically distributed infrastructure of research centers and user facilities that house leading edge equipment. The NNI also works with the private sector and State and regional stakeholders to facilitate technology transfer of NNI R&D results, thus advancing nanotechnology development efforts for commercial and public benefit. The NNI also aids scientific advancement and commercialization through education and workforce preparation programs.

As part of these efforts to advance nanotechnology, the Federal Government supports a coordinated program, with participation by both research and regulatory agencies, to understand potential health and environmental effects of nanotechnology. In addition, the NNI is expanding its activities in outreach and public engagement as part of its efforts to assess and address societal and ethical concerns associated with this emerging area of technology.

Nanotechnology is a priority element of the American Competitiveness Initiative (ACI) that was announced by the President in his 2006 State of the Union address, and over half of the FY 2007 NNI budget is going to the agencies that are targeted by the ACI (i.e., the National Science Foundation, Department of Energy Office of Science, and the National Institute of Standards and Technology). As described in this report, the NNI is taking steps to leverage resources across all agencies to ensure that the Federal program leads to the expeditious and responsible development of nanotechnology for the Nation's benefit and in support of our continued global leadership.

Sincerely,



John H. Marburger, III
Director

Table of Contents

Tables and Figures

Executive Summary

Overview

The National Nanotechnology Initiative (NNI), now in its sixth year, is a highly successful, collaborative, cross-cutting program among 25 Federal agencies, 13 of which have budgets for nanotechnology research and development (R&D). With the strong support of this Administration and Congress, the NNI has been and will continue to be a major driver for the responsible development of nanotechnology in the United States and the world. Because of the NNI, (1) Federal agencies have initiated major new nanotechnology R&D activities that support national goals and agency missions; (2) there is an extensive and growing infrastructure of nanotechnology research and education centers; and (3) the 25 participating agencies (see Table 1, p. v) are working together to maximize the effectiveness of their individual and collective investments through communication, coordination, and joint programs.

The NNI is an important supporting component of the President's American Competitiveness Initiative (ACI) announced in the 2006 State of the Union address. The ACI supports the technological innovation that drives the U.S. economy through policies that stimulate private investment and entrepreneurship and that improve the ability to attract and retain the best and the brightest to high technology study and work. Within Federal agencies, the ACI calls for increased spending for physical science research, improved math and science education, and training to ensure a skilled U.S. workforce for the 21st century. The goals of the ACI and the NNI are aligned. In particular, proposed spending for physical science research called for in the ACI and included in the President's 2007 Budget includes nanotechnology R&D programs described in this report.

The vision of the NNI is a future in which the ability to understand and control matter on the nanoscale leads to a revolution in technology and industry. Agencies participating in the NNI continue their dedication to the goals outlined in the December 2004 NNI Strategic Plan (nano.gov/html/about/strategicplan2004.html). These goals are:

1. **Maintain a world-class R&D program**
2. **Facilitate technology transfer**
3. **Develop educational resources, a skilled workforce, and supporting research infrastructure and tools**
4. **Support responsible development of nanotechnology**

The NNI Strategic Plan also outlines seven major subject areas for investment, called program component areas (PCAs), under which related projects are grouped.

This Supplement to the President's 2007[1] Budget serves as the annual report for the NNI called for by the 21st Century Nanotechnology Research and Development Act (Public Law 108-153). The report provides details of the NNI budget for the current year (2006) and the proposed budget for 2007, broken out by program component area. This report also includes information on spending for the development and acquisition of research facilities and instrumentation, a discussion of external reviews of the NNI and how recommendations are being addressed, a description of how the NNI participating agencies are implementing the NNI Strategic Plan, and a summary of nanotechnology R&D funding through the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs.

Budget Summary

The 2007 NNI budget request for nanotechnology R&D across the Federal Government is nearly $1.3 billion, an increase of 21% over the 2006 request[2]. Estimated spending in 2006 is over $1.3 billion, an increase of 8.6% over 2005 expenditures. Over the last six years, spending for nanotechnology has nearly tripled from an estimated $464 million in 2001. The increase reflects this

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. 2006 figures can be found in the NNI Supplement to the President's FY 2006 Budget, available at www.nano.gov/NNI_06Budget.pdf.

Administration's continuing strong support for the NNI program, based on its potential to expand knowledge, strengthen the U.S. economy, support national and homeland security, and enhance the quality of life for all citizens.

The five agencies investing the most in nanotechnology R&D (i.e., National Science Foundation, Department of Defense, Department of Energy, National Institutes of Health, and National Institute for Standards and Technology) each have investments distributed across at least six of the seven PCAs. Funding among the PCAs by all 13 agencies with nanotechnology R&D budgets reflects a balanced strategic investment. Planned 2007 funding by PCA is as follows:

1. Fundamental Nanoscale Phenomena and Processes ($401 million)
2. Nanomaterials ($250 million)
3. Nanoscale Devices and Systems ($263 million)
4. Instrumentation Research, Metrology, and Standards for Nanotechnology ($77 million)
5. Nanomanufacturing ($41 million)
6. Major Research Facilities and Instrumentation Acquisition ($164 million)
7. Societal Dimensions ($82 million)

All the agencies participating in the NNI are still adjusting to the analysis and use of PCAs for categorizing their investments in nanotechnology R&D, which began in 2006. Quantitative estimates are provided based on selections of programs or projects that best match the PCA definitions provided in the 2004 NNI Strategic Plan. With this qualification and a reminder that any conclusions about trends are based on only two years of data, the major changes in the 2007 funding are slight decreases in funding for PCA 2 (Nanomaterials) and PCA 3 (Nanoscale Devices and Systems), and funding increases in PCA 4 (Instrumentation Research, Metrology, and Standards for Nanotechnology), PCA 5 (Nanomanufacturing), and PCA 6 (Major Research Facilities and Instrumentation Acquisition). With the same qualifications, planned 2007 funding for PCA 1 (Fundamental Nanoscale Phenomena and Processes) and PCA 7 (Societal Dimensions) has remained relatively unchanged.

The Societal Dimensions PCA includes approximately $44 million for programs that are directed primarily at environmental, health, and safety (EHS) R&D, up from a 2006 requested funding level of $38.5 million. Interagency planning and coordination in this area is expanding. The Societal Dimensions PCA further includes $38 million for education-related activities and research on the broad implications of nanotechnology for society, including economic, workforce, educational, ethical, legal, and other social implications.

Changes in the NNI for 2006 and 2007: Highlights

The NNI underwent a substantial structural change in 2005 with the implementation of the December 2004 NNI Strategic Plan. The vision, goals, and program component areas that were outlined in that plan were reflected for the first time in the NNI Supplement to the President's 2006 Budget, released in March 2005. These overall drivers for the NNI remain the same for 2007. This report therefore focuses on the significant progress that has been made toward achieving those goals since the release of the NNI Supplement to the President's 2006 Budget. Some highlights that have taken place since the release of that document or that are planned for 2007 follow:

- The advanced infrastructure of research centers and user facilities that supports the entire spectrum of nanotechnology R&D is being substantially augmented. The number of centers and user facilities in operation will exceed 50 in 2006 and will grow further in 2007. Funded jointly and individually by several agencies, the facilities, instrumentation, and expertise are a key component of the NNI.
- Individual multiyear projects, as well as the overall portfolio of research, aimed at understanding the potential environmental, health, and safety implications of nanotechnology continue to mature and grow. The Nanoscale Science, Engineering, and Technology (NSET) Subcommittee's Nanotechnology Environmental and Health Implications (NEHI) Working Group coordinates activities among agencies with research and regulatory responsibilities. NEHI is in the process of

preparing a document that identifies EHS research needed to enable risk assessment of nanoscale materials, products, and processes.

- NSET Subcommittee members continue to participate in and provide financial support for the American National Standards Institute's Nanotechnology Standards Panel (ANSI-NSP) and the ANSI-accredited Technical Advisory Group (TAG) to the International Organization for Standardization Technical Committee on Nanotechnologies (ISO TC 229). Support of these efforts to develop common terminology and other standards is very important for advancing nanotechnology applications and commercialization. Three major topics are being pursued by the ANSI TAG to ISO TC 229: (1) general terminology and nomenclature for nanotechnology, (2) metrology and instrumentation for nanotechnology, and (3) health, safety, and environmental aspects of nanotechnology. Within the efforts of the ISO TC 229, the United States is leading the international efforts to develop standards on health, safety, and environmental aspects of nanotechnology.
- The President's Council of Advisors on Science and Technology (PCAST) released its first report in May 2005 in its capacity as the National Nanotechnology Advisory Panel (NNAP), assessing the first five years of the NNI and making a number of useful recommendations for future improvements. That report is discussed in some detail in the sidebar on page vi.
- Following release of the NNAP report, the NSET Subcommittee of the Committee on Technology of the National Science and Technology Council began implementing some of the NNAP's recommendations. Specifically, the NSET Subcommittee has:
  - Reached out to the Department of Education and the Department of Labor with the result that they have joined the NNI as participants. This will facilitate enhanced coordination of the Federal Government's efforts to address education and workforce issues associated with nanotechnology.
  - Addressed the NNAP's recommendation to increase the NNI's outreach to and coordination with the States, by organizing and conducting a second workshop on "Regional, State, and Local Initiatives in Nanotechnology" on November 3-4, 2005. The workshop provided a forum for interchange of ideas among the leaders of regional, state, and local nanotechnology initiatives and identified means to promote continued success of those initiatives and to strengthen the role of the States in achieving NNI goals.
- The NSET Subcommittee member agencies, through the National Nanotechnology Coordination Office (NNCO), provided substantial input to and support of the National Academies' evaluation of the NNI in 2005, with expectation of a report release in 2006. Consideration and implementation by the NNI of recommendations will begin in late 2006 and continue through 2007.
- The NNI, through the National Nanotechnology Coordination Office and other channels, is broadening its activities for public engagement in 2006 and 2007.
- Agency-specific highlights are summarized briefly here, with more detail on the changes for 2006 and 2007 provided in Section 1 of this report.
  - DOD: Support continues for program activities seeking to discover and exploit unique phenomena at nanoscale dimensions to enable novel applications that enhance warfighter and battle systems capabilities. Support also continues for nanomaterials research to enable robust incorporation and design of nanoscale phenomena and the realization of novel materials properties based on these phenomena. Added support for nanomanufacturing research is anticipated via the SBIR/STTR and Manufacturing Technology (MANTECH) programs in order to facilitate transition to and a supply of nanotechnology-based products for defense technologies.
  - DOE: Physical construction of four of the five Nanoscale Science Research Centers will be completed in 2006, and full operations will be supported at these major user facilities

in 2007; a fifth center will remain under construction. The 2007 request includes a substantial increase in funding for research at the nanoscale, largely for activities related to the hydrogen economy, solar energy conversion, fundamental studies of materials at the nanoscale, and instrumentation for characterizing materials at the nanoscale.

- EPA: With an almost 100% increase in nanotechnology-related R&D funding for 2007, EPA will continue to focus the majority of research in 2006 and 2007 on the potential health and environmental implications of nanomaterials; increased efforts in the area of risk assessment and risk management needs for nanomaterials; and research on nanoscale technologies as potential solutions to environmental problems.

  EPA has released a draft white paper for public comment that looks broadly at how various environmental statutes can and will be applied to protect public safety and the environment with respect to nanotechnology. This white paper is the point of departure for additional activities such as developing a research strategy and implementing programmatic activities.

- FDA: Several new nanotechnology-based biomedical device applications of nanotechnology have been approved, including nanocomposites for orthopedic and dental applications.

- NIH: Continued significant ramp-up of nanotechnology R&D funding includes implementing the Nanomedicine Roadmap Initiative; the National Cancer Institute's Nanotechnology Platform Partnerships and Nanotechnology Characterization Laboratory; the National Heart, Lung, and Blood Institute's Programs of Excellence in Nanotechnology; and the Nanotechnology Program Area at the National Institute of Biomedical Imaging and Bioengineering.

- NIOSH: Emphases include release of an initial document with recommended practices for safe handling of nanomaterials in the workplace, and formation of Nanotechnology Field Teams that are conducting field studies in partnership with stakeholders to observe and assess occupational health and safety practices and control technologies in facilities where nanotechnology processes and applications are used.

- NIST: Several new programs are being initiated to develop physical standards and measurement methods for engineered nanoscale materials, to accelerate their use in new classes of materials, and to aid in assessing environmental impact. NIST has established the Center for Nanoscale Science and Technology and the Advanced Measurement Laboratory, and is applying these and other existing resources and expertise to the development of leading nanotechnology and nanomanufacturing measurement science.

- NSF: Prominent initiatives include a new focus and corresponding program announcement on "Active Nanostructures and Nanosystems," implementation of the Center for Hierarchical Nanomanufacturing, and increased support for fundamental research in the physical sciences and materials at the nanoscale.

- USDA: The Forest Service has joined the NNI budget crosscut, with a budget request for 2007 of $2.1 million focused on applications of nanotechnology to enhance utilization of forest resources and research on low-cost forest product feedstocks for nanomanufacturing.

Organization of the Report

- Section 1 describes the NNI R&D programs under each of the seven PCAs, including specific strategic priorities, highlights of the 2007 budget request, interagency coordination activities, and a brief overview of activities underway or planned by each participating agency for 2006 and 2007.

- Section 2 provides detailed budget information by agency and PCA and summaries of agency areas of emphasis for 2006 and 2007. Section 2 also provides information on agency use of the SBIR and STTR programs to achieve NNI goals, and it describes coordinated interagency activities in

the following areas of emphasis: environmental, health, and safety research; nanomanufacturing; industry liaison in support of technology transfer and commercialization; standards development; infrastructure development; and interdisciplinary research. Finally, Section 2 summarizes changes in NNI agency activities.

- Appendices include a glossary, agendas of the open meetings of the National Academies as part of their review of the NNI, and contact information for agency staff involved in the NNI.

Table 1
List of Federal Agencies Participating in the NNI During 2006

Federal agencies with budgets dedicated to nanotechnology research and development
Cooperative State Research, Education, and Extension Service (CSREES, Department of Agriculture)
Department of Defense (DOD)
Department of Energy (DOE)
Department of Homeland Security (DHS)
Department of Justice (DOJ)
Department of Transportation (DOT)
Environmental Protection Agency (EPA)
Forest Service (FS, Department of Agriculture)
National Aeronautics and Space Administration (NASA)
National Institute of Standards and Technology (NIST, Department of Commerce)
National Institute for Occupational Safety and Health (NIOSH, Department of Health and Human Services/ Centers for Disease Control and Prevention)
National Institutes of Health (NIH, Department of Health and Human Services)
National Science Foundation (NSF)
Other participating agencies
Bureau of Industry and Security (BIS, Department of Commerce)
Consumer Product Safety Commission (CPSC)
Department of Education (DOEd)
Department of Labor (DOL)
Department of State (DOS)
Department of the Treasury (DOTreas)
Food and Drug Administration (FDA, Department of Health and Human Services)
International Trade Commission (ITC)
Intelligence Technology Innovation Center (ITIC)
Nuclear Regulatory Commission (NRC)
Technology Administration (TA, Department of Commerce)
U.S. Patent and Trademark Office (USPTO, Department of Commerce)

External Reviews of the National Nanotechnology Initiative

The 21st Century Nanotechnology Research and Development Act (Public Law 108-153, hereafter referred to as the Act), which was signed into law by President Bush in December 2003, calls for a triennial external review by the National Research Council of the National Academies of several aspects of the National Nanotechnology Initiative, including its technical accomplishments, the appropriateness of agency funding levels, successes in technology transfer, and consideration of societal interests. As called for in the Act, the National Nanotechnology Coordination Office has commissioned the first of these reviews. Members of the NSET Subcommittee briefed a National Academies review committee at all five of its open meetings in 2005 (see agendas, Appendix B), and provided substantial additional background materials. A final report is expected in 2006.

The National Research Council (NRC) reviewed the National Nanotechnology Initiative previously in 2002. An analysis of the recommendations of the 2002 NRC report and how the NNI has responded to its recommendations was included in the NNI Supplement to the President's Budget for 2006.

In July 2004, PCAST was designated as the National Nanotechnology Advisory Panel (NNAP) called for by the Act. The NNAP has ongoing responsibilities for providing an assessment of and recommending improvements for the NNI. In May 2005, PCAST released its first report in its capacity as the NNAP (www.nano.gov/html/res/FINAL_PCAST_NANO_REPORT.pdf). The report addresses four key questions: (1) Where do we stand? (2) Is this money well spent and the program well managed? (3) Are we addressing societal concerns and potential risks? and (4) How can we do better? The following is a summary of PCAST's answers to these questions:

> The United States is the acknowledged leader in nanotechnology R&D. The U.S. Federal Government investment is roughly one-quarter of the current government investment by all nations and is leveraging even larger investments by private companies as well as State and local governments. The United States leads in the number of start-up companies based on nanotechnology and in research output as measured by patents and publications. The U.S. leadership position, however, is under increasing competitive pressure from growing public and private activities around the world.
>
> The money the United States is investing in nanotechnology is well spent; the recent NNI Strategic Plan provides an appropriate way to organize and manage the program; and the NNI's coordinated interagency approach and its efforts to interact with industry and the public are laudable. Continued robust funding is important for long-term U.S. economic well-being and national security.
>
> The NNI recognizes that the societal implications of nanotechnology—including environmental and health effects—must be taken into account and is moving deliberately to identify, prioritize, and address such concerns.
>
> While the overall assessment of the NNI in this report is positive, PCAST offers the following recommendations aimed at further strengthening the NNI:
>
> - *Technology Transfer*—To further facilitate technology transfer from the lab to the marketplace, the NNI should expand efforts to dialogue with U.S. industry, increase Federal-State coordination, and improve knowledge management of and access to NNI assets, e.g., user facilities and instrumentation.
> - *Environmental and Health Implications*—The NNI should continue its efforts to understand the possible toxicological effects of nanotechnology and where harmful human or environmental effects are proven, pertinent Federal agencies should apply appropriate regulatory mechanisms. The report calls for strong interagency collaboration as well as international coordination on this issue.
> - *Education/Workforce Preparation*—The NNI should establish relationships with the Departments of Education and Labor to develop education and training systems to improve the Nation's technical proficiency in areas related to nanotechnology.
> - *Societal Implications*—The NNI must support research aimed at understanding societal (including ethical, economic, and legal) implications of nanotechnology and must actively work to inform the public about nanotechnology.

The NSET Subcommittee and the NNI agencies are acting upon these recommendations. For example, the NNI agencies reached out to the Departments of Education and Labor and they have become members of the Subcommittee; a second workshop on Regional, State, and Local Nanotechnology Initiatives was held; and research centers on Nanotechnology in Society were established. Details of these and other activities that respond to the PCAST report's recommendations are included within the program highlights elsewhere in this report.

1. NNI Research by Program Component Area

National Nanotechnology Initiative (NNI) research in each of seven program component areas (PCAs) is described in this section in terms of the following outline:

- PCA title.
- NNI agencies participating in the PCA, including those with and without budgets for nanotechnology research and development (R&D) in this area. Inclusion in the list of participating agencies indicates a significant relationship to the agency's mission, interest, or needs. Standard acronyms are used for agency names; see Table 1 or the glossary in Appendix A for the full names of agencies.
- A brief description of why the PCA is important for the overall vision and goals of the NNI.
- A list of long-range strategic interests underlying the 2007 budget request in the PCA. Strategic interests and activities bridge multiple agencies and encompass a broad range of topics, including specific topics for R&D, targets for particular applications, goals for research and development, functional goals for infrastructure, and milestones for educational programs and public engagement.
- A list of selected 2007 programmatic highlights in the PCA. The highlights are specific tactical approaches within the long-range strategic areas, generally bridging across multiple agencies.
- A summary of interagency planning and coordinating activities supporting the 2007 request in the PCA.
- A concise description by agency of the major programs within the PCA that are underway in 2006 and planned for 2007. The descriptive section for each PCA is not intended to be a thorough overview of the nanotechnology programs of the agencies.

Planning and Coordination Across PCAs

Several NNI planning and coordination activities support all the PCAs:

- Participation in the Nanoscale Science, Engineering, and Technology (NSET) Subcommittee of the Committee on Technology of the National Science and Technology Council enables coordination of activities under all of the PCAs among the participating agencies, for example, through participation in proposal evaluations, program reviews, and workshop planning.
- A number of agencies with regulatory responsibilities—CPSC, EPA, FDA, NRC, OSHA, USDA—participate in the NNI and its working groups to coordinate with research agencies and support the NNI vision and goals. Such coordination helps inform regulatory decision-making and also helps guide the programs at the research agencies. The readiness of regulatory agencies to address materials, devices, and other nanotechnology-based products will have significant impact on this technology's success as an engine for economic growth and public benefit.
- All NNI agencies share an interest in enhancing awareness of, and where appropriate, engaging in international R&D activities.
- In the past year, the USDA Forest Service, the Department of Labor, the Department of Education, and the DOD's Defense Threat Reduction Agency (DTRA) joined the NSET Subcommittee. The Forest Service is requesting a budget of $2.1 million for nanotechnology R&D in 2007, which will facilitate enhanced interagency planning and coordination in the Fundamental Nanoscale Phenomena and Processes; Nanomaterials; Nanoscale Devices and Systems; Nanomanufacturing; and Societal Dimensions program component areas. The Department of Education and the Department of Labor are joining NSET but do not have specific nanotechnology R&D

budgets. However, their participation is expected to enhance interagency coordination, especially with regard to PCA 7, Societal Dimensions, in helping NSET address the educational and workforce issues associated with the continued development and exploitation of nanotechnology.

The Defense Threat Reduction Agency is funding studies to examine how nanotechnology can enhance chemical and biological defenses and is collaborating with other NNI agencies, in particular DOE.

PCA 1: Fundamental Nanoscale Phenomena and Processes

NNI Agencies Requesting 2007 Funding for R&D Related to This PCA: ***DHHS (NIH), DOC (NIST), DOD, DOE, DOT (FHWA), EPA, NASA, NSF, USDA (CSREES), USDA (FS)***

Other Participating Agencies: ***CPSC, DHS, DOC (BIS), DOC (TA), DOJ, ITIC***

The overarching aim of coordinated NNI funding for Program Component Area 1 is to advance the knowledge frontiers of nanoscale phenomena and processes toward the goal of systematic control over matter at the nanoscale. Such advanced knowledge is a foundation for innovation in all application areas for nanotechnology. Representative R&D includes discovery and understanding of the basic science of collective electron, optical, and magnetic phenomena; biological and biochemical mechanisms; and quantum size effects in nanoscale and nanostructured matter. All these processes and phenomena play a key role in, for example, development of novel DNA sequencing techniques; new energy conversion technologies; development of new sensors for use in detecting pathogens or toxins in food and agricultural systems; and detecting chemical, biological, radiological, or explosive agents.

President's 2007 Request

Strategic Priorities Underlying This Request

Federal agencies involved in this PCA have identified the following critical R&D areas as essential for discovery, understanding, and application of nanotechnology:

- Enhanced surface and interface effects arising at the nanoscale
- Basic science of self-assembly, directed self-assembly, programmed self-assembly, biologically driven self-assembly processes, and other processes necessary for manipulating and controlling matter at the nanoscale
- Basic research on nanoscale phenomena and processes such as collective electron, optical, and magnetic phenomena in assemblies of nanostructures to advance innovation in data storage and data processing systems
- New mathematical and simulation capabilities and tools with high spatial and temporal resolution, such as virtual laboratories and immersive visualization, to guide experimental investigations
- Application of novel tools and concepts emerging from nanotechnology to improve understanding of biological processes
- Biomedical mechanisms for improved diagnostics, therapeutics, and treatments of disease
- Quantum size effects for improved light sources and photovoltaic cells and, in combination with surface effects, for application in unique catalysts
- Dynamic events at the nanoscale, particularly with respect to ultrafast phenomena, including chemical bond formation
- Fundamental physics of nanoscale processes such as manipulating single charges in nanostructures and devices typified by Josephson junctions, single-electron tunneling devices, and quantum Hall effect devices

Highlights of the 2007 Request

- Investigation of principles of assembly and positional control of nanoscale objects (such as nanotubes, nanowires, quantum dots, etc.) with potential to create devices, arrays, or systems via self-assembly, templated assembly, and biologically assisted assembly
- Basic research on nanoscale phenomena and processes for application to hydrogen production, hydrogen storage, hydrogen-based fuel cells, and nanotechnology-based batteries and capacitors, in support of a hydrogen economy
- Research on the synthesis, characterization, properties, and assembly of individual nanostructures, including nanostructures in biology and for catalysis
- Merging nanotechnology-enabled measurements with fundamental biomedical research to generate novel insights into disease mechanisms and treatment options; and discerning the design of biological systems to guide future nanotechnology systems designs

Interagency Planning, Coordination, and Collaboration Supporting the 2007 Request

DOD, DOE, NASA: Coordinating research efforts in directed energy conversion.

DOD, DOE, NASA, NIH, NIST, NSF: Developing and operating centers of excellence and user facilities to support R&D on this PCA.

EPA, NASA: Jointly developing a testing technique and methodology for the identification, characterization, and correlation of carbon nanotubes and combustion processes.

NASA, NIST: Collaborating in carbon nanotube research highlighted by a joint workshop.

Trans-NIH: Coordinating the Nanomedicine Roadmap Initiative and two nanoscience and nanotechnology program announcements (including one for Small Business Innovation Research, SBIR) across the institutes and centers of the NIH.

2006 and 2007 Activities by Agency

DHHS (NIH): Use novel tools and concepts emerging from nanotechnology to improve understanding of biological processes. Much of biomedicine is based on cellular and subcellular (molecular and macromolecular) phenomena, so nanotechnology offers unique opportunities for measurement and manipulation in this biologically important size scale.

While much of biology is grounded in nanoscale phenomena, NIH has not reclassified most of its basic research portfolio as nanotechnology. Projects are classified as nanotechnology when any of the following criteria is met: nanotechnology tools and concepts are used to study biology; engineering approaches are applied to the development of new nanoscale devices and systems for the early detection and treatment of diseases; proposals are made to engineer biological molecules toward functions very different from those they have in nature; or proposals involve manipulation of biological systems by methods more precise than can be achieved by using molecular biological, synthetic chemical, or biochemical approaches that have been used for years in the biology research community.

Under the Nanomedicine Roadmap Initiative launched in 2004, NIH funded four Nanomedicine Development Centers in 2005 and will expand the centers program in 2006. The initial goal is to develop and apply new tools with which to extract quantitative information on macromolecular systems in living cells or organisms, generating far more complete predictive models of biology at the molecular and longer length scales than are available today. In the process, engineering principles underlying biology will be developed. In later stages of the program, these discoveries will be used to develop systems for healthcare.

Other NIH programs related to this PCA include (a) the National Institute of General Medical Sciences program area entitled *Single Molecule Biophysics and Nanoscience*; (b) a portion of the National Heart, Lung, and Blood Institute and National Cancer Institute (NCI) nanotechnology programs (with the majority of funding under the PCA on Nanoscale Devices and Systems); (c) a portion of the NCI's Integrative Cancer Biology program; (d) a portion of the National Human Genome Research Institute program to develop novel DNA sequencing

technologies (with additional work under the PCA on Nanoscale Devices and Systems), which will develop new fundamental knowledge needed to support device development; and (e) several projects under the NIH Roadmap Initiative on Molecular Libraries and Imaging to develop fundamental new approaches for molecular imaging in biological systems.

DOC (NIST): Continue development of the Center for Nanoscale Science and Technology (CNST) and the Advanced Measurement Laboratory to establish a measurement infrastructure for the electronic, magnetic, and optical properties of nanostructures; devise ways to build "designer nanostructures" on an atom-by-atom basis; perform first-principles simulations of the structure and dynamics of nanoscale systems; and develop methods and devices for quantum information processing. Other areas of emphasis include the following:

- Investigation of the chemical forces that control electrical interplay between molecules in contact in moletronic devices
- Development of quantum-based standards and measurement techniques for industrial applications
- Characterization and modeling of the nanoparticle/polymer matrix interface to provide an understanding of the dispersion of nanoparticles in polymer matrices and to provide enhanced performance properties (such as durability, conductivity, scratch resistance, etc.) of polymer nanocomposites
- Development of fundamental knowledge at the nanoscale spatial and molecular levels on where, how, and why materials undergo chemical and physical degradation at nanoscale dimensions when they are exposed to the environment

DOC (TA): Monitor developments in the areas covered by the PCA, facilitate dissemination of this new knowledge to representatives of the business community, and examine their implications for U.S. domestic and international policies.

DOC (USPTO): Pursue efforts in the following two areas of relevance to all of the PCAs:

- The Nanotechnology Customer Partnership, whose objectives include exchange of information, cooperative efforts to provide patent examiners with in-depth technical training on the state of the art in nanotechnology, and identification of the best sources of nanotechnology-related information. Activities within the partnership include specific nanotechnology-related patent examiner training and continued work on the cross-reference art collection of 263 subclasses for nanotechnology, designated Class 977 and entitled "Nanotechnology." Appropriate classification will allow examiners to more easily locate relevant technical information, thereby improving patent quality.
- Ongoing discussions with the "Trilateral Offices" partners—the European Patent Office and the Japan Patent Office—regarding nanotechnology-related patent examining issues facing all three offices, including search and documentation issues and substantive examination issues.

DOD: Discover new phenomena and processes to enable breakthrough advantages for warfighter and battle systems capabilities; develop robust strategies for synthesis, characterization, and assembly of individual nanostructures; explore applications of nanostructures for revolutionary catalysis, chemical and biological agent scavengers, taggants, and sensors; and elucidate fundamental aspects of phonon and electron transport in individual nanowires and two- and three-dimensional nanostructures as they relate to the development of high-performance thermoelectric, thermionic, and photovoltaic devices for advanced solid-state power generation, cooling, and thermal management.

DOE: Support fundamental scientific research into nanoscale phenomena via grant programs and DOE National Laboratory research efforts, including investigations of mechanisms of hydrogen production and storage and of solar energy conversion. Research surface and interfacial chemical phenomena; catalysis; nanoparticle reactivity; photochemistry at the nanoscale; electronic, optical, magnetic, thermal, mechanical, and other materials properties; nanoscale organic-inorganic hybrids and interfaces; theory, modeling, and simulation; and advanced scientific computing. Investigate principles of assembly and positional control of nanoscale objects (such as nanoparticles, nanotubes, nanowires, quantum dots, etc.) to create devices, arrays, or systems via self-assembly, templated assembly, and biologically assisted assembly. Develop and analyze novel X-ray, neutron,

electron, and other scattering phenomena to investigate dynamic and ultrafast processes at the nanoscale.

EPA: Develop innovative characterization approaches using high-resolution transmission electron microscopy to detect and characterize engineered nanoscale materials emitted from nanotechnology applications and conventional processes. Using nanotechnology tools and methods, EPA plans to fingerprint physical characteristics of engineered nanoscale materials, with special interest on C_{60} fullerenes. Engineered nanoscale materials are being used and researched in industry for a wide variety of applications including surface coatings, improving fiber optics, and improving battery and capacitor technology. Some baseline understanding of the levels of these molecules in the environment, their formation mechanisms, and analytical techniques needed to identify their presence is fundamental to assessing engineered nanoscale materials in the environment and their potential risks. During 2006 and 2007, EPA plans to further characterize the properties of engineered nanostructures by layer, separation distance, curvature, and tortuosity using statistical fringe analysis.

NASA: Pursue the strategy of using the biological model of hierarchical cellular organization for the application of nanotechnology and for the management of information as a paradigm for future space systems and explorers. Using real-time feedback loops, conduct research at the intersection of biology and nanotechnology to develop (a) a bio-analytical laboratory for interrogating extraterrestrial samples, (b) high-density transducer arrays for providing high-throughput, quantitative physiological monitoring for astronauts, and (c) diagnostic technologies for spacecraft environmental monitoring. The long-term goal is to capitalize on Nature's model for the management of information, achieving complex functionality through the self-organization of a large number of primitive information inputs.

NSF: Support individual investigator research, interdisciplinary research, and education teams (small groups), science and engineering centers, and exploratory research. A funding priority for 2007 will be in the area of understanding and potential application of quantum effects, collective behavior, and other nanoscale phenomena.

Special emphasis will be placed on research in the following areas:

- Novel phenomena, quantum control, and basic engineering processes, i.e., discovering and understanding phenomena and design processes specific at the nanoscale, including collective behavior, new physical and chemical phenomena, and their implementation in mechanics, biology, electronics, and optics. A particular focus will be on collective behavior at the nanoscale—experimental and theoretical research aimed ultimately at understanding and controlling fundamental physical and chemical interactions and emergent behavior at the nanoscale. Potential applications include quantum computing and new devices and processes for advanced communications and information technologies.
- Biosystems at the nanoscale: study of biologically based or inspired systems that exhibit novel properties enabling useful applications. Potential applications include exploitation of functions of cellular organelles and biomolecular motors; devices for research in genomics, proteomics, and cell biology; and biomedical applications such as improved drug delivery, biocompatible nanostructured materials for surgical implantation, and miniature sensors for diagnostics, e.g., for early detection of cancer.
- Collective electron, optical, and magnetic phenomena in assemblies of nanostructures to advance innovation in data storage and data processing systems.
- Merging science and engineering at the nanoscale: the convergence of nanotechnology with information technology, modern biology, and social sciences will stimulate discoveries and innovation in almost all areas of the economy. This theme includes investments in (a) nano-biology interface research and (b) nano-information technology interface research.
- Multiscale, multiphenomena theory, modeling, and simulation at the nanoscale to support large-scale computer simulation and new design tools and infrastructure in order to understand, control, and accelerate development in new nanoscale regimes and systems. Research on theory, mathematical methods, modeling, and simulation of physical, chemical, and biological systems at the nanoscale will include techniques such as quantum mechanics and quantum chemistry, multiparticle simulation,

molecular simulation, grain and continuum-based models, stochastic methods, and nanomechanics. A special focus will be on understanding and control of fundamental interactions among nanoscale components at various length scales and exposed to various surrounding conditions (temperature, pressure, magnetic and electric field, light intensity, etc.).

USDA (CSREES): Research nanoscale phenomena and processes with significant implications for improving biological production, processing, and preservation. Research sensing mechanisms useful to ensure food safety and biosecurity, preserve and track product identity, improve environmental quality, and enhance production and process efficiency. Research promotion of optimal human health through novel delivery mechanisms of bioactive ingredients in foods.

USDA (FS): Conduct fundamental research on nanoscale properties and behavior of wood and its constitutive nanocomponents in order to help capture the value of wood-based lignocellulosic materials and their nanoscale architectures. This includes nanoscale phenomena and processes such as decay, photo degradation, and adhesion that require a range of test methods and metrologies to evaluate performance and accurately predict service life. Researchers from the Forest Products Laboratory will evaluate lignocellulosic materials, their degradation mechanisms, and chemical treatments to mitigate degradation using a range of chemical and nanoscale instrumentation (dynamic mechanical analysis, nanoindentation, atomic force microscopy, and X-ray tomography) to detect initial stages of wood deterioration in both preservative-treated and untreated wood products.

PCA 2: Nanomaterials

NNI Agencies Requesting 2007 Funding for R&D Related to This PCA: ***DHHS (NIH), DOC (NIST), DOD, DOE, DOJ, EPA, NASA, NSF, USDA (CSREES), USDA (FS)***

Other Participating Agencies: ***CPSC, DHHS (FDA), DHHS (NIOSH), DHS, DOC (BIS), DOC (TA), DOC (USPTO), DOT, DOTreas, ITC, ITIC***

Program Component Area 2 recognizes that nanomaterials are the key to successful development of nanotechnology for a host of potential future applications ranging from computers and communications to healthcare. Commercial exploitation of nanotechnology will require precisely designed and controlled synthesis and processing of nanomaterials and a fundamental understanding and control of their properties and behavior. For some applications, simple nanostructured materials will suffice; for others, complex, hierarchically structured nanomaterials will be required. Examples of nanostructured materials include high-density data storage media; metals with augmented mechanical properties and lower susceptibility to corrosion; ceramics that are cheaper to manufacture and that have more forgiving failure modes; new generations of energy storage materials; materials for improved healthcare, including advanced drug delivery systems; and composites with multifunctional capabilities enabled by the design freedom offered by hierarchical structures.

President's 2007 Request

Strategic Priorities Underlying This Request

- Uniform, reproducible synthesis and processing of research quantities of nanomaterials
- Harnessing of biological processes and nanoscale biomaterials for low-cost synthesis and templating of designed nanostructures
- Research on nanomaterials for use in sensing and detection, identity preservation and tracking, controlled delivery and release of therapeutic agents, and design of nanoengineered therapeutic tissues

- Research on nanocomposites for applications including lightweight, high-strength materials for transportation vehicles and civil infrastructure, and on packaging materials with improved barrier and mechanical properties
- Development of precision nanostructure synthesis techniques required to provide process control over quantum transport characteristics of devices utilizing nanostructured materials
- Development of an improved knowledge base of information on chemical and biological properties of nanoscale materials to evaluate their uses for improving the environment and human health, and to avoid possible adverse implications
- Research focused on nanobiotechnology for improving biological production, processing, and preservation, and development of value-added novel materials and products to benefit agriculture and society
- Development of high-strength, lightweight materials useful for space systems and other high-performance applications
- Development of new adhesives and thermal protection materials for aerospace applications

Highlights of the 2007 Request

- Research on controlled self-assembly and guided assembly of novel engineered nanoscale materials and hierarchical structures
- Basic nanomaterials research for the hydrogen economy
- Accelerated research in the areas of nanomechanical property measurements (e.g., elastic properties, hardness, strength, friction and adhesion, residual stress/strain, interatomic potentials); nanotube/nanoparticle metrology; critical dimensions; size distribution; electronic properties; structure; surface composition; separation by size and electronic properties; and biological properties
- Research on characterizing and exploiting emergent properties of materials and hierarchical assembly of functional nanostructures from the molecular scale, including nanostructured catalysts, and materials of agricultural and biological origins
- Intensified research on the use of nanotechnology and nanoscience approaches to design and develop new dental composite materials with superior properties
- Initiation of a USDA Forest Service program to investigate use of crystalline cellulose and chemically or biologically modified cellulose to fabricate new lightweight, high-performance composites
- Research on bridging length scales from nano to micro to macro, to enable production of real-world materials that benefit from nanoscale processes, phenomena, and properties

Interagency Planning, Coordination, and Collaboration Supporting the 2007 Request

DHS, NIST: Application of carbon nanotubes for improved fire resistance of construction materials, and investigation of the efficacy of engineered semiconductor nanoscale materials deposited on the surface of construction materials for deactivating biological agents and for decomposing hazardous chemicals.

DOC (BIS, TA), DOS, and other NNI agencies: Support for the work of the President's Export Council's separately chartered Subcommittee on Emerging Technologies to maximize the economic potential of nanomaterials while simultaneously protecting the security interests of the United States.

DOD, DOE, DOT, EPA, NASA, NIST, NSF, USDA: Collaboration and cooperation on the Hydrogen Research and Development (R&D) Interagency Task Force of the National Science and Technology Council, which also includes the U.S. Postal Service.

DOD, DOE, NSF: Ongoing collaborative research efforts in nanostructured materials.

DOD, NASA, NSF: Coordinated development of modeling and simulation tools for predicting properties of nanoscale materials and for developing and optimizing processes for nanomaterials fabrication.

DOE, NIST: Coordinated activity in nanotube characterization at Brookhaven National Laboratory.

FDA, NIH (NCI), NIST: Collaboration to address characterization of nanomaterials for biomedical applications.

NASA, NIST: Collaboration to develop measurement protocols for nanotubes and other nanoscale materials.

2006 and 2007 Activities by Agency

DHHS (NIH): Research is being conducted on development of innovative and body-friendly implantable materials based on biological nanostructures with desired physical, mechanical, and chemical properties, with shapes and textures that mimic extracellular matrix, for regeneration of damaged tissues. Goals are to construct "smart" multifunctional particles to target specific cells or tissues, sense medically relevant physiological or molecular signals, locally deliver measured doses of antibiotics or other therapeutics to reduce unwanted drug side effects, and intervene at the earliest stages of disease.

Within the National Cancer Institute's Nanotechnology Characterization Laboratory (further described under PCA 4, Instrumentation Research, Metrology, and Standards), the focus is on developing a characterization cascade for use in preclinical evaluations of nanomaterials intended for cancer therapeutics.

At the National Institute of Dental and Craniofacial Research, efforts are focusing on research leading to the development of nanostructured composite materials that are biocompatible, maintain the appearance of native teeth, and provide improved importance and longevity over the existing dental restorative materials.

DHHS (NIOSH): Populating the Nanoparticle Information Library, which provides base information about physical, chemical, and hazard properties of existing nanomaterials. This effort is being coordinated with other NNI agencies through the NSET Subcommittee to implement and maintain current guidance for the research community, industry, and the public on appropriate practices and strategies for safe handling of nanomaterials.

DHS: Materials with nanoscale structure are under development for use in threat detection and related applications. Nanomaterials of interest include carbon nanotubes, block copolymers, ceramic and metallic nanoparticles, nanoporous ceramic and metallic microstructures and devices, and biomaterials and biomimetic structures. Chemical modification and assembly of nanostructured materials for threat detection applications is also of interest.

DOC (NIST): Development of measurements and standards to advance innovation and application of nanomaterials across all technology sectors. For example, programs to advance metrology of optical materials at the nanoscale will include multiphoton luminescence spectroscopy and refractive index measurements of group III-nitride semiconductors and improved growth methods and characterization of semiconductor quantum dots. Additionally, NIST is pursuing research on chemically functionalizing carbon nanotubes for use in chemical force microcopy, chemical sensors, and polymer nanocomposites to enhance physical and fire-resistant performance of polymeric materials. Characterizing material properties for nanoimprint lithography is also a growing area within NIST.

DOC (USPTO): Support the high level of commercial patenting activity in nanomaterials as described in the section on PCA 1, Fundamental Nanoscale Phenomena and Processes.

DOD: Research is underway to develop the precision nanostructure synthesis techniques required for a high degree of process control over quantum transport characteristics of devices utilizing nanostructured materials; to harness biological processes for low-cost synthesis and templating of designed nanostructures; to control and exploit interactions between synthetic and naturally occurring (biological) materials; and to develop nanoscale architectures to enhance local diffusion behavior, reaction kinetics, optical properties, and electrical properties.

DOE: Research is going forward on structure and evolution of nanostructured materials; X-ray, neutron, and electron scattering characterization; response to external stimuli such as temperature, fields, and

concentration gradients; phase transformations; mechanical behavior; radiation-induced defect cascades and amorphization; theoretical and computational models linking nanoscale structure to macroscale behavior; controlled synthesis mechanisms and process science, including self-assembly; organic and polymeric nanoscale systems; functionalized nanostructures and nanotubes; and novel nanoscale and nanostructured materials for hydrogen production, storage, and use, and for photovoltaics and other energy-conversion purposes.

EPA: In 2005, EPA synthesized and tested novel adsorbent materials designed to remove mercury and other air pollutants from the flue gas emissions of stationary combustion sources such as coal-fired power plants. In 2006, tests will be conducted in larger bench-scale equipment and in a pilot-scale combustion system. Additional characterization of the materials will be conducted to determine specific sorbate-sorbent bonding mechanisms and other physico-chemical properties. In 2007, additional performance data will be collected with the goal being eventual full-scale testing and implementation of this technology at a commercial coal-fired power plant.

NASA: Research will continue into nanomaterials with properties desired for future space systems, including large size per mass (for ultralarge apertures, solar sails, etc.) and high strength per mass (for launch vehicles, human habitats in space, etc.). R&D includes (a) development of predictive models/simulations to guide materials and processing design; (b) development of fundamental understanding of synthesis, growth, and nano-macro structure development mechanisms; (c) integration of physical and chemical forces with external fields to get desired properties during processing as well as development of the ability to control synthesis and manufacturing processes over all length scales; (d) development of inexpensive methods for production of highest-quality nanomaterials; and (e) development of adaptable synthesis, processing, and characterization methods to efficiently utilize resources of other planets.

NSF: Research aimed at discovery of novel nanoscale and nanostructured materials and at a comprehensive understanding of the fundamental properties of nanomaterials (ranging across length scales, and including interface interactions). Controlled design and synthesis of nanostructured materials with targeted properties, including ceramic, metal, polymeric, biomolecular and composite materials. Self-assembly and guided assembly of novel materials. Examples of possible benefits that could arise from this basic nanomaterials research include molecular electronics, nanostructured catalysts, thermal processes in nanostructures, advanced biomedical devices, quantum computing, development of high-capacity computer memory chips, two- and three-dimensional "designed" nanostructures, biophotonics, control of surface processes, and lubrication. Four new Materials Research Science and Engineering Centers awarded since 2001 focus on nanomaterials research.

USDA (CSREES): Research in the following major areas: (a) nanoscale biomaterials of agricultural origins for novel uses; (b) nanomaterials that can be used in sensing and detection for food safety and biosecurity, identity preservation and tracking, and controlled delivery and release of functional contents; (c) novel biocatalysts; and (d) nanocomposite materials for various applications (e.g., improved barrier and mechanical properties of packaging materials).

USDA (FS): Research and new instrumentation will be directed to understand the unique performance properties of wood fibers and their hierarchical architecture composed of cellulose, hemicellulose, and lignin polymers. Applications are expected primarily in two areas: alteration of solid wood to improve properties, and use of nanofibers in lightweight, high-performance composites.

Forest Products Laboratory scientists will be focusing their efforts on the following programs:

- Examination of selective chemical modification of specific wood nanoscale domains to enhance the strength of solid wood and adhesively bonded wood assemblies
- Development of nanoscale sol-gel wood coatings for improved resistance to ultraviolet light degradation and color change, and of biocides embedded in polymer matrices to address the need for new environmentally compatible preservatives

- Investigating the effects of nanoclays as additives and nanomaterials to alter the surface chemistry of biofibers to develop high-performance wood-plastic composites and engineered biocomposites
- Exploring nanoscale and nanostructured materials for a newly proposed biomass conversion system and chemical synthesis process

The Forest Service has procured new and enhanced instrumentation for evaluating materials at the nanoscale that will become completely operational during 2006. With reassignment of personnel to the nanomaterials program in 2007, this instrumentation will support a fully developed program.

PCA 3: Nanoscale Devices and Systems

NNI Agencies Requesting 2007 Funding for R&D Related to This PCA: ***DHS, DHHS (NIH), DOC (NIST), DOD, DOE, EPA, NASA, NSF, USDA (CSREES), USDA (FS)***

Other Participating Agencies: ***CPSC, DHHS (FDA), DOC (BIS), DOC (TA), DOC (USPTO), DOJ, DOT, DOTreas, ITC, ITIC, NRC***

Program Component Area 3 focuses on the applied research and development needed to transition rapidly into technological application the multitude of scientific discoveries in nanoscale phenomena, processes, and materials. Many of the truly dramatic benefits from nanoscale science and engineering research arise when the unique properties of nanostructures and nanomaterials are engineered into useful devices and systems that take advantage of those properties. Such innovation in devices and systems grows from understanding the fundamental properties of individual nanostructures and of nanomaterials. The development of nanoscale devices and systems is expected to have broad applications across a variety of industries with significant economic benefits. For example, nanostructures will enable new devices for data gathering, logic, storage, and transmission, all of which will be incorporated into future-generation information systems.

President's 2007 Request

Strategic Priorities Underlying This Request

The development of practical device and systems applications of nanoscale science and technology remains a top priority for the NNI. The strategic priorities underlying this PCA include the following:

Overarching Priorities

- Accelerating the transition of scientific discoveries into practical technologies for both civilian and defense applications
- Creating science and engineering platforms—materials systems or models that can be used as a stage or scaffolding for generic classes of experiments—thereby enabling reliable and reproducible experiments across a range of nanoscale materials or structures
- Developing biomimetic devices and systems for simultaneously improving understanding of biological structures and enabling processes important to nonbiological applications
- Investigating nanostructures and nanoscale devices that can detect, prevent, or remediate failure processes in materials

Application-Oriented Priorities

Aerospace

- Ultrasensitive and selective sensor devices

Agriculture and Food

- Biomimetic devices for agricultural production and food quality/safety, with spin-offs in human health and environmental quality
- Nanostructure approaches to extend the applications of wood and wood products

National Defense and Homeland Security

- Exploration of the implications of nanotechnology for the security of information technology systems, including (1) identification of security threats, objectives, and requirements, as well as associated security metrics, and (2) a testbed to identify challenges in developing security solutions for information technology systems built from nanoscale devices
- Enhancing capabilities of the individual warfighter
- Incorporation of high-performance materials and information control in autonomous platforms for enhanced warfighting with minimal risk to the individual warfighter
- Nanostructures for enhanced sensitivity and selectivity in chemical, biological, and explosive detection, enhanced adsorption in protective equipment, and enhanced remediation
- Nonvolatile, radiation-hard, low-power, high-density, random access memory

Energy

- High-efficiency solar energy conversion devices
- Solid-state lighting with improved efficiency over incandescent and fluorescent technologies
- Low-cost fuel cells, batteries, thermoelectrics, and ultracapacitors
- Reversible hydrogen storage materials operating at ambient temperatures

Environment

- Improved knowledge of nanoscale devices and systems to evaluate their uses for improving the environment and to mitigate any possible adverse implications
- Nanostructures capable of remediating polluted and other hazardous waste sites
- Demonstration of miniature and inexpensive technologies for rapid, continuous, simultaneous detection of multiple environmental contaminants

Information Technologies

- Support for complementary research, in collaboration with industry, aimed at exploring the limits of CMOS technology, particularly as CMOS devices are scaled down to the sub-100 nm level
- New nanodevices (such as Si-based quantum devices, molecular electronics, spintronics, optoelectronics, and organic thin-film transistors) to supplement or supplant the CMOS devices that are currently used by the semiconductor industry
- Investigation of the potential for nanostructures to implement quantum physics approaches to revolutionary information technologies

Medicine and Health

- Use of knowledge from fundamental investigation of biological systems and nanomaterials to develop systems for diagnosing and treating disease that are highly specific and effective and that minimize adverse effects
- Multifunctional devices for controlled delivery and release of micronutrients and bioactive compounds, and assessment and reporting of physiological condition
- Medical devices and systems to diagnose, prevent, and treat debilitating conditions such as cancer, heart disease, and nervous system injury

Transportation and Civil Infrastructure

- Condition-based sensing for reducing infrastructure maintenance costs
- Better concrete through the exploitation of nanostructures

Highlights of the 2007 Request

- ☐ Extended efforts to develop a variety of mission-specific nanoscale devices described below in "2006 and 2007 Activities by Agency"

- Thrusts on innovative architectures to best exploit nanostructures in information technologies, including quantum computing and quantum communications
- Addition of USDA/FS funding for research in this PCA, including assignment of Forest Service personnel to nanotechnology programs that will move from the screening stage to more fully developed programs
- Applications of semiconductor nanowires, including development of electrically addressable nanowire lasers for homeland security and biomedical applications
- R&D focused on the theme "Silicon Nanoelectronics and Beyond," including evaluation and review with input from the semiconductor industry
- Continued growth of nanoelectronics device research in the "base" programs of appropriate agencies, e.g., exploratory research on replacing electron charge with alternative information carriers such as electron spin, electron phase, or molecular state
- Accelerated research and development on novel nanoscale sensors for defense, homeland security, agricultural, and industrial applications. Examples include nanobarcodes for product identity preservation and tracking and nanotechnology-based devices for high-throughput screening

Interagency Planning, Coordination, and Collaboration Supporting the 2007 Request

All NNI agencies: Recently published and forthcoming NSET-sponsored workshop reports including "Nanobiotechnology" and "Nanoelectronics, Nanophotonics, and Nanomagnetics" that will provide guidance to agencies in formulating their nanodevice and nanosystems research programs.

DOD, DOE, NASA, NIST, NSF: Coordinated research efforts focused on the realization of robust quantum computing.

DOD, DOE, NASA, NSF: Cooperative efforts on materials, device development, and modeling for direct thermal-to-electrical energy conversion (thermoelectric, thermophotovoltaic, and thermionic).

DOD, DOE: Cooperative efforts between DOD (ARO) and DOE (Sandia National Laboratories) to develop monolithic absorber/bolometric sensors for terahertz detectors.

DOD, DOE, NASA, NSF: Coordinated programs for nanostructured electrodes and catalysts for fuel cells and batteries.

DOD, NSF: Collaboration with the Semiconductor Research Corporation to develop the next generation of nanometer-scale lithography technology.

EPA, DOE, USDA (CSREES): Ongoing EPA collaboration, begun in 2005, with USDA/CSREES and with DOE in the area of pervaporation, specifically membranes constructed of a polymer-zeolite composite and a zeolite-only matrix where the zeolites have nanoscale pores; continued partnerships are planned through 2006 and 2007.

NSF and other NNI Agencies: Organization of an academic-industry-government workshop on integration of nanoscale devices and systems in microsystems, of joint workshops with other agencies, and of student exchanges with researchers from Germany, Japan, Korea, France, and other countries.

USDA (CSREES) with other NNI agencies: Developing a better understanding of nanotechnology-based sensors.

2006 and 2007 Activities by Agency

DHS: Focus on sensing devices based on single-wall carbon nanotubes, conducting nanoparticle ensembles, semiconducting nanowires, and nanostructured microscale devices; chemical modification of nano- and microscale devices to effect enhanced interface interactions or modified physical properties; and novel chemical sensing transduction mechanisms or signal enhancements associated with nanostructured devices.

DHHS (FDA): FDA product centers have established working/communication groups and internal training

programs that identify potential nanotechnology products subject to FDA regulation.

Maintain the website www.fda.gov/nanotechnology/ to explain FDA's approach to reviewing nanotechnology-enabled products.

Assist in development of analytical methods suitable for characterization of therapeutic products based on nanotechnology, which will be required to develop useful manufacturing process controls and lot release tests.

DHHS (NIH): Continue to support the development of new nanoscale devices and systems for the early and specific detection of disease before pathology has substantially damaged the body; treatment of disease by use of directed methods that reduce undesirable side effects; monitoring of treatment efficacy; and repair of tissue that is damaged due to inborn conditions and trauma (e.g., accidents, disease, environment, battlefield injury).

At the National Cancer Institute (NCI), the Alliance for Nanotechnology in Cancer (nano.cancer.gov/) has funded eight Centers of Cancer Nanotechnology Excellence to serve as hubs to develop and apply nanotechnology devices and systems to the diagnosis, prevention, and treatment of cancer. The NCI Alliance has also awarded multidisciplinary cancer nanotechnology fellowships and twelve cancer nanotechnology platform development partnerships. These Alliance program activities are fully integrated with existing NCI programs and resources; funding initiated in 2005, will continue through 2006, and is requested for 2007.

At the National Human Genome Research Institute, the "$1000 Genome" program, initiated in 2004, expanded in 2005, and continuing through 2007, explores the development of nanosensors the size of individual DNA molecules for the rapid, inexpensive sequencing of DNA for use in medicine, sensors, etc.

At the National Heart, Lung, and Blood Institute, Programs of Excellence in Nanotechnology seek to apply nanotechnology to the diagnosis and treatment of heart, lung, blood, and sleep diseases. Another program goal is to train a cadre of investigators with the skills required to apply nanotechnology to this research.

At the National Institute of Neurological Disease and Stroke, programs support research to reduce the burden of neurological disease by investigating nanotechnology as a tool to study the development, structure, and function of the brain. Nanoscale devices will be used for *in vivo* imaging and drug delivery, with utility for clinical assessment, diagnosis, and treatment of disorders of the nervous system.

DOC (NIST): Develop the theoretical underpinnings needed to enable the engineering of practical quantum computing devices. Other devices are being developed for quantum communications and for materials analysis of nanoscale contaminants in semiconductor manufacturing via microcalorimetry.

DOC (TA): Continue to monitor developments in nanoscale devices and systems and facilitate dialogue between industry, government, and academic research communities to accelerate commercialization of products based on nanotechnology.

DOD: Utilize breakthroughs in nanotechnology to provide revolutionary devices and systems to advance warfighter and battle systems capabilities.

Establish a detailed understanding of nanoscale behavior related to electrochemical power source applications (batteries with enhanced discharge rate and energy density; high-energy-density capacitors; direct thermal-to-electrical energy conversion), fuel cell catalysts, and electrode structures.

Engage the DOD applied research and development communities to accelerate the transition of scientific discovery into DOD-relevant technologies.

Work with the Director, Defense Research and Engineering Advisory Group on Electron Devices (AGED), U.S. Navy groups developing technology plans for Carrier Technology (CARTECH), Submarine Technology (SUBTECH), and Surface Ship Technology (SURFTECH) programs, the U.S. Army Research, Development, and Engineering Command (RDECOM) Nanotechnology Integrated Product Team, and the Air Force Research Laboratory Nanoscience and Technology Strategic Technology Team to examine future platform opportunities and requirements.

DOE: Conduct research on electronic, magnetic, and optical properties of nanostructures, including quantum dots, nanoscale particulate assemblies, and lithographically produced nanoarrays.

Research confinement effects in nanoscale and molecular devices and on contacts and interfaces leading to development of novel sensor concepts and lab-on-a-chip systems, and integration of nanoscale devices and components.

Initiate applied programs to leverage nanotechnology for improving fossil and renewable energy conversion, storage, and use.

EPA: Research pervaporation membranes constructed of polymer-particle matrices in which the particles are nanoscale or contain nanoscale pores. Such membranes will be used for the energy-efficient recovery of biofuels such as ethanol from process waste streams and for the removal of trace amounts of water from ethanol for fuel applications. Continue partnership with industry and USDA in 2006 to develop high-performance membranes and conduct bench-scale testing of this technology. Perform pilot-scale studies in 2006 and work to transfer the technology to larger-scale private enterprises.

Continue the relationship in 2006 with an industrial partner and DOE to test nanoporous zeolite membranes under real-world conditions, including the use of actual biomass fermentation streams. Through 2007, EPA will support DOE in development of high-efficiency solvent/fuel dehydration membranes, including those containing nanoparticles.

Support small businesses to develop nanoscale technologies and instruments for sensing, treatment, remediation, and prevention of pollution. Support development of new nanoporous filters for removal of gaseous pollutants and particulates from contaminated air streams; nanoparticulate catalysts for utilization in volatile organic compound treatment devices and related applications; microelectromechanical systems (MEMS) and nanotechnology-based devices for use in environmental analytical and monitoring instruments (including sensors and nanocomponents); and a personal sampling device for the detection and quantification of airborne nanoparticle exposures.

NASA: Research and develop nanoscale sensors and instrumentation that enhance remote sensing, vehicle health and performance monitoring, astrobiological and geochemical research, and manned spaceflight.

Research properties of structures that are determined not only by the layering of materials, but also by the three-dimensional shape of nanocomponents and their interaction properties.

Address challenges facing development of nanoscale sensors, including (a) production and refinement, (b) manipulation and control, (c) lithography, (d) macro-micro-nano integration, (e) toxicology, (f) robust and reliable architectures, (g) self-calibrating networks, and (h) data fusion.

NSF: Begin a new focus on research on active nanostructures and nanosystems, and continue collaboration with the electronics and semiconductor industries on research related to "Silicon Nanoelectronics and Beyond."

Focus research on both advanced silicon nanotechnology devices and on post-CMOS electronic, magnetic, and optical devices—research that explores the ultimate limits to scaling of features and examines alternative physical principles for devices employed in sensing, storage, communication, and computation, including biological, molecular, and other emerging areas of electronics at the nanoscale.

Continue R&D that applies the principles of nanoscale science and engineering to create novel, or to improve existing, devices and systems. Incorporate nanoscale or nanostructured materials to achieve improved performance or new functionality.

Develop new concepts to understand interactions among nanoscale devices in complex systems, including the physical, chemical, and biological interactions between nanostructures and device components.

Conduct interdisciplinary research on methods for design of systems composed of nanodevices, including multiple layers of abstractions and various mathematical models to represent component behavior in different layers.

Develop each of the following: (a) new tools for sensing, assembling, processing, and manipulating nanostructures and devices; (b) techniques for manufacturing and device

integration from nanoscale to macroscale; (c) methods for controlling and testing nanostructures and devices; (d) design and architecture concepts; (e) specialized software for nanosystems; and (f) design automation tools for assembling systems of large numbers of heterogeneous nanocomponents, including fluidics and robotics.

USDA/CSREES: Develop new sensors for improving agricultural production, enhancing food quality and safety, tracking product history, improving human health through optimal nutrition, and monitoring and improving environmental quality.

USDA/FS: Conduct R&D focused on incorporation of nanoscale materials, devices, and systems to improve the end-use performance of and add multifunctional capabilities to forest products.

USPTO: See the section on PCA 1, Fundamental Nanoscale Phenomena and Processes.

PCA 4: Instrumentation Research, Metrology, and Standards for Nanotechnology

NNI Agencies Requesting 2007 Funding for R&D Related to This PCA: *DHHS (NIH), DOC (NIST), DOD, DOE, DOJ, NSF, USDA (FS)*

Other Participating Agencies: *CPSC, DHHS (NIOSH), DHS, DOC (BIS), DOC (TA), DOC (USPTO), DOT, EPA*

Instrumentation, metrology, and standards are key links in the chain from discovery to commercialization. Program Component Area 4 aims to advance the boundaries of knowledge in instrumentation and metrology and to bring state-of-the-art tools and techniques to bear in the development of standards for the nanotechnology community. Support of scientific instrument development enables new investigations that were previously not possible and may open up entire new fields of scientific inquiry.

Advances in tools for measurement and characterization of matter at the nanoscale have expanded knowledge and are integral to nanoscale R&D. On the other hand, the desire to be able to make measurements that are not possible today drives the development of even more powerful tools. Instrumentation to probe the nanoscale requires not just evolutionary improvements, but revolutionary developments in measurement schemes and instruments. Advances in this PCA impact all the PCAs and are vital to the overall success of the NNI. The ability to accurately and reproducibly measure the properties and performance characteristics of nanoscale materials, devices, and systems is a critical enabler for progress in fundamental nanoscience, in the design of new nanomaterials, in evaluating environmental, health, and safety impacts, and ultimately in the manufacture of new nanoscale products. This ability is also necessary for monitoring and protecting human health and the environment.

President's 2007 Request

Strategic Priorities Underlying This Request

To meet the emerging needs of the nanotechnology industry, the NNI's investment strategy for this PCA balances further evolution and standardization of current tools and methods with creation of entirely new tools and techniques. Priorities include R&D in the following areas:

- Revolutionary new techniques, tools, and instruments that enable major advances in spatial, temporal, and energy resolution limits
- Instrumentation combining sub-nanometer spatial resolution with chemical specificity and full three-dimensional mapping of the atomic or molecular structure of nanomaterials and nanodevices at all points within their volume

- Enhancement of the U.S. nanometrology infrastructure supporting commercial manufacture of advanced products and development of nanoscale manufacturing
- Development of terminology and nomenclature that defines the growing number of nanostructures in a manner compatible with conventional molecular nomenclature
- Standardization of measurement techniques, nomenclature, and testing methodologies to facilitate assurance of quality, safety, and efficacy of nanoproducts, and their effective regulation and production
- Development of measurements and standards for nanomaterials that will provide the critical infrastructure for manufacturing and commercialization of nanotechnology
- Development and verification of advanced simulation, visualization, and data analysis techniques and supporting standards

Highlights of the 2007 Request

- Strong advocacy for and participation by NSET Subcommittee members in the American National Standards Institute's Nanotechnology Standards Panel (ANSI-NSP) and the ANSI-accredited Technical Advisory Group (TAG) to the International Organization for Standardization Technical Committee on Nanotechnologies (ISO TC 229). Support of these efforts to develop common terminology and other standards needed to advance nanotechnology applications and commercialization. Three major topics are being pursued by the ANSI TAG to ISO TC 229: (1) general terminology and nomenclature for nanotechnology, (2) metrology and instrumentation for nanotechnology, and (3) health, safety, and environmental aspects of nanotechnology. Within ISO TC 229, the United States is leading the international efforts to develop standards on health, safety, and environmental aspects of nanotechnology. NNI agencies will be supporting in part a 2007 meeting in the United States of the Health, Safety, and Environmental Working Group of ISO TC 229.
- Major emphasis on advancing the state of the art of microscopies and analytical instrumentation for nanotechnology R&D, e.g., scanning probe microscopes, scanning and transmission electron microscopes, and electron, neutron, and photon spectroscopies.

Interagency Planning, Coordination, and Collaboration Supporting the 2007 Request

NIH (NCI), NIST, FDA: Collaboration on tools and methodologies for nanoparticle metrology, and development of the National Cancer Institute (NCI) Nanotechnology Characterization Laboratory analytical cascade to assess physical, *in vitro*, and *in vivo* properties of nanomaterials.

NIST, NASA: Collaborative development of measurement protocols for nanotube characterization and fabrication.

NNI agencies and NNCO: Coordination and provision of funding and staff support for the ANSI Technical Advisory Group and ISO Technical Committee activity described above.

2006 and 2007 Activities by Agency

DHHS (NIH): Characterize and validate the suite of instrumentation to be used by the NCI's Nanotechnology Characterization Laboratory (NCL). The NCL aims to provide critical infrastructure and characterization services to nanomaterial providers in order to accelerate the transition of basic nanoscale particles and devices into clinical applications, thereby reducing suffering and death from cancer. The NCL will serve as a national resource and knowledge base for all cancer researchers to facilitate the regulatory review of nanotechnologies intended for cancer therapies and diagnostics. The NCL is described further under PCA 7, Societal Dimensions.

DOC (NIST): Establish the Center for Nanoscale Science and Technology (CNST) at NIST to support development of new metrology instrumentation, methods, and artifact standards for U.S. nanotechnology efforts.

Support the development, at an elevated level, of a new measurement infrastructure essential to a wide variety of applications research, including such novel instruments as:

- Innovative atomic force microscopes (AFMs) including an atomic force acoustic microscope for nanomechanical property measurement and an AFM-based chemical microscopy technique using functionalized nanoprobes and carbon nanotubes to measure chemical properties of materials at nanoscale spatial resolution
- High-energy-resolution X-ray microcalorimeters for materials analysis of nanoscale contaminants that can undermine nanomanufacturing processes
- Electron microscopy and spectroscopy instrumentation for quantitative three-dimensional chemical imaging at the nanoscale
- State-of-the-art variable pressure scanning electron microscopy with traceable metrology capabilities
- Methodologies and techniques for characterizing the photo and catalytic activities of engineered nanoscale materials and nanopigments
- Methodologies and techniques for fabricating, characterizing, and modeling nanomaterials used for highly fire-resistant materials and firefighter protection

DOC (USPTO): Activities designed to support the high level of commercial patenting activity in instrumentation research, metrology, and standards for nanotechnology are described in the section on PCA 1, Fundamental Nanoscale Phenomena and Processes.

DOD: Develop breakthrough next-generation instrumentation to support research on advanced nanotechnology-based materials and devices; extend magnetic force microscopy and enable robust single-spin measurement devices; extend new measurement capabilities into innovative sensors for use in defense missions.

DOE: Proceed with development of a transmission electron aberration-corrected microscope (TEAM), a major instrument innovation taking advantage of recent advancements in correction of electromagnetic lens defects to reach previously unobtainable performance levels. The design and realization of TEAM is a multiyear project involving five DOE-supported electron scattering research groups with substantial involvement of equipment manufacturers to develop a next-generation electron microscopy platform.

Also, employ new beam line instrumentation at neutron scattering centers and synchrotrons to facilitate investigation of nanostructures. Enhancement of beam line instrumentation will continue in 2007 to provide unprecedented capabilities for dynamic characterization of nanomaterials properties such as structure and composition.

NIOSH: Establish a suite of instruments and protocols for characterizing nanomaterials in the workplace environment; develop and evaluate methods to assess worker exposure to engineered nanomaterials using available instruments and methods; characterize and measure engineered nanomaterials release, dispersal, and migration; conduct measurements of individual exposures to engineered nanomaterials; evaluate both current and developing instrumentation and methods for monitoring exposure to engineered nanomaterials; evaluate engineering control methods for engineered nanomaterials; and provide recommendations for reducing worker exposure to engineered nanomaterials.

NSF: Support R&D pertaining to new nanotechnology tools, including next-generation instrumentation for characterization, measurement, synthesis, and design of materials, structures, devices, and systems, and particularly for temporal and spatial high-resolution imaging and measurement of nanoscale domains of scientific, systems engineering, and biological relevance. The Office of Interdisciplinary Activities' Major Research Instrumentation program is a major contributor to NSF program activities in this area.

USDA (FS): Develop new measurement techniques at the Forest Products Laboratory for forest and paper products, and implement a broad plan for nanomaterials metrology research in the Forest Service research program.

Many techniques have been developed for measuring uniform surfaces of metals, ceramics, and coatings. However, these techniques must be modified to deal with rough and less homogenous surfaces that exist with lignocellulosic materials. Development of instrumentation and measurement techniques must provide key information about the properties of nanoscale domains of wood and cellulosic fibers. Standard techniques such as nanoindentation, surface

probe microscopy, atomic force microscopy, and scanning electron microscopy, along with surface preparation techniques such as focused ion beam and ion polishing systems, can be used for preparation and analysis of wood and surfaces. Finally, a surface-enhanced Raman spectroscopy technique using nanometer-sized silver particles can allow the Raman spectra of lignin to be detected without interference from cellulose.

In 2006, funding has been used to acquire new and enhanced instrumentation that will be made fully operational in the coming year. In 2007, more personnel will be assigned to develop the preferred analytical techniques.

PCA 5: Nanomanufacturing

NNI Agencies Requesting 2007 Funding for R&D Related to This PCA: ***DHHS (NIH), DOC (NIST), NASA, NSF, USDA (CSREES), USDA (FS)***

Other Participating Agencies: ***DHHS (NIOSH), DOC (BIS), DOC (TA), DOC (USPTO), DOD, DOE, DOT, EPA, ITC, ITIC***

Program Component Area 5 is focused on nanomanufacturing. Development of the capability to manufacture nanoscale materials and devices is key to realizing the potential benefits of nanotechnology for society. Nanomanufacturing is taken here to include all means that have the capability to reproducibly transform matter—from a bulk form or from individual atoms, molecules, and supramolecular structures—into nanoscale or nanostructured materials, devices, or systems with desired properties and performance characteristics, typically in large quantities.

Additionally, nanomanufacturing includes the capability to integrate such nanoscale materials and devices into systems spanning nanoscale to macroscale dimensions. NNI programs in this area support the development of nanomanufacturing capabilities, including tools and processes for the modeling, design, and manufacture of nanomaterials, nanostructures, and nanosystems. Research and development programs address new methods for design, simulation, and production that enable scaled-up and cost-effective manufacturing of nanoproducts in the expectation that nanomanufacturing will be one of the principal technologies impacting the future of manufacturing in general. As processes are scaled from laboratory prototyping to fabrication of products, reproducibility and testability become critical, as do regulatory oversight and approval processes.

President's 2007 Request

Strategic Priorities Underlying This Request

- Research into use of self-assembly, directed self-assembly, programmed self-assembly, biologically driven self-assembly, and scanning-probe-based techniques for control of matter at the nanoscale, including biologically inspired processes and techniques, and research into methods for integrating manufactured nanoscale products into larger application structures
- Development of process control and quality control in manufacturing at the nanoscale based on traceable metrology
- Research and development on precompetitive nanomanufacturing problems such as scale-up and reproducibility of nanomanufacturing processes
- NSET Subcommittee coordination with other Federal efforts to enhance the manufacturing infrastructure of the United States, thereby providing jobs and other economic benefits

- Efforts to seek and utilize advice from the electronics, chemical, and other industries to sharpen the NNI program
- Development and demonstration of manufacturing processes that incorporate nontoxic constituents and that use less energy, water, and other resources

Highlights of the 2007 Request

- Continued development of the NIST Center for Nanoscale Science and Technology (CNST) and nanomanufacturing and nanofabrication programs
- Establishment of a network for nanomanufacturing based on an NSF Center for Hierarchical Nanomanufacturing, including other NSF Nanoscale Science Engineering Centers (NSECs), DOD Multidisciplinary University Research Initiative (MURI) sites, and the NIST CNST
- Identification of appropriate opportunities to introduce nanomanufacturing into the DOD Manufacturing Technology (MANTECH) program
- Establishment of multiple programs to develop new metrology and characterization tools suitable for manufacturing environments
- NSET Subcommittee participation in the National Science and Technology Council (NSTC) Interagency Working Group on Manufacturing Research and Development (IWGM)

Interagency Planning, Coordination, and Collaboration Supporting the 2007 Request

DOC (NIST, TA), NSF, DOD: Leading in establishing collaboration between the NSTC Interagency Working Group on Manufacturing Research and Development and the NSET Subcommittee.

DOD, NSF, NIST: Coordination of program plans and program reviews for development of R&D partnerships and for the nanomanufacturing R&D efforts highlighted above.

USDA, NSF: Developing new understanding of nanobiomaterials and nanobiodevices that may be integrated into novel applications in nanomanufacturing.

2006 and 2007 Activities by Agency

DHHS (NIOSH): Continue to develop and expand research, information, education, and recommendation-based programs to facilitate the integration of good occupational safety and health practices in nanomanufacturing.

DOC (NIST): Continue planning to develop the necessary instrumentation, measurement science, and standards, as well as establish the materials and process characterization needed by industry for nanoscale manufacturing. Additionally, in support of the Administration's emphasis on nanotechnology and manufacturing, NIST has identified the Center for Nanoscale Science and Technology as a top priority within the agency. It provides centralized access to NIST's unique nanometrology facilities and nanofabrication resources, including the new Advanced Measurement Laboratory (AML), by researchers from industry, academia, and government. The CNST leverages the AML and broad metrology expertise across many disciplines at NIST to provide outstanding measurement capabilities for industry. By focusing on removing barriers to U.S. innovation in nanomanufacturing, the CNST directly addresses the R&D needed for this PCA and does so by converting science into technology for manufacturing.

Support nanomanufacturing via new investments in NIST activities to develop:

- New dimensional test standards with atomic precision capability and integrity and standards for autonomous atom assembly
- Optimized fabrication tools to manipulate and probe physical and chemical properties of materials at the nanoscale
- New intrinsic calibration systems for basic physical properties
- Methods for nanomanipulation of soft materials
- New, optimized high-resolution imaging and measurement methods for carbon nanotubes, fuel cells, and biological samples
- Improvements to fast, high-resolution positioning stage (154-picometer-resolution readout at rates of over 2 MHz)

- Tungsten nanotip electron emitters for higher-resolution electron microscopy
- Delivery of artifact standards for production metrology instruments, including linewidth, overlay, and 2D positioning

Additionally, emphasis is being placed on developing new metrologies in support of nanomanufacturing, including:

- Algorithms, devices, and systems to enable online process control of dimension and material composition
- Measurements of force dissemination for quantitative nanomechanical testing
- Novel fabrication platforms for testing functionality and operation of nanoimprint lithography, nanojet deposition, and other nanodevices
- A database of properties of atomic and molecular interactions among various materials to facilitate autonomous atom-by-atom assembly of nanostructures
- Measurements to assess functional and mechanical reliability of products during manufacturing

DOD: Guide and monitor the introduction of nanotechnology into military hardware; identify appropriate opportunities to introduce nanomanufacturing into the DOD SBIR, STTR, and MANTECH programs; enable the synthesis, generation, and assembly of individual nanostructures using lessons drawn from biology, including the use of viruses and related structures as templates for nanowires and for arrays of inorganic materials of particular interest; and develop affordable manufacturing approaches to nanostructured bulk materials.

It should be noted that Section 2 indicates zero DOD investment in PCA 5 because individual DOD research efforts addressing this PCA are primarily focused on other PCAs (i.e., PCA 2, Nanomaterials, and PCA 3, Nanoscale Devices and Systems). While numerous accomplishments in Nanomanufacturing have been made via defense research investments, and additional activities are underway as described above, these accomplishments have been made under research efforts aligned more closely with the objectives of another PCA.

DOE: Develop modular microlaboratories for collaborative work at the DOE Nanoscale Science Research Centers, such as the Center for Integrated Nanotechnologies' "discovery platforms," and other activities for the investigation of nanomanufacturability and related R&D on manufacturing processes.

EPA: Support development of nanotechnology-based process technologies that provide greener, more environmentally friendly manufacturing processes. Of particular interest are nanotechnologies that reduce the use and release of toxic pollutants, especially persistent, bioaccumulative toxics, hazardous air pollutants, and volatile organic compounds. Examples include nanostructured coatings for dry machining, metal-free nano-laminated coatings, and nanomaterials with smart characteristics, including reactive coatings that destroy or immobilize toxic compounds. Additional areas for support include R&D on high-surface-area nanomaterials for new coatings and environmental applications, and development of technology for solvent-free production of nanometer-size high-performance ceramic powders and similar materials.

NSF: Support R&D aimed at enabling scaled-up, reliable, cost-effective manufacturing of nanoscale materials, structures, devices, and systems, including novel concepts for high-rate synthesis and processing of nanostructures and nanosystems. Ultraminiaturized top-down processes and increasingly complex self-assembly (or other bottom-up) processes are being explored. Biosynthesis and bioprocessing methods will be developed for the manufacture of biochips and novel biomaterials, improved delivery of bioactive molecules, engineering of nanoscale sensory systems, and modification of existing biomolecular machines for new functions. Awards have been made through the Nanomanufacturing Program in the Directorate for Engineering, through other NSF core programs, and in response to the research and education theme in the NSF-wide program solicitation. In April 2006, NSF made an award to the University of Massachusetts, Amherst, for the establishment of a Center for Hierarchical Nanomanufacturing and expects this center to become fully operational in 2007.

PCA 6: Major Research Facilities and Instrumentation Acquisition

NNI Agencies Requesting 2007 Funding Related to This PCA: *DHHS (NIH), DOC (NIST), DOD, DOE, NSF*

Other Participating Agencies: *DOC (TA), DHS, NASA*

The NNI continues to invest substantial resources in establishing large multidisciplinary centers and user facilities as mechanisms to bring together and foster collaboration among groups of researchers from many disciplines. These centers and user facilities (see chart, page 23) also provide access to advanced and often costly instrumentation. The number of centers and user facilities in operation will exceed 50 in 2006 with the addition of up to four more NIH Nanomedicine Development Centers, the opening of three more DOE Nanoscale Science Research Centers (NSRCs), and awarding of the NSF Center for Hierarchical Nanomanufacturing. Provision of these resources is a critical component of the NNI goal to develop the supporting infrastructure and tools to advance nanotechnology and allows exploration of all the best ideas in nanoscience and nanotechnology by ensuring that leading-edge capabilities are broadly available. User facilities are readily accessible on a merit basis to researchers from academia, government, industry, and other research organizations. Access to centers focused in specific areas of research or application is available through collaboration with center researchers. Physical or computational facilities are geographically spread across the country to ensure easy access; individual facilities include distributed networks with multiple nodes, in addition to single-site centers. Included in Program Component Area 6 are facility planning, facility design and construction activities, acquisition and commissioning of instrumentation for nanoscience and nanotechnology research, and ongoing operation of instrumentation and facilities.

President's 2007 Request

Strategic Priorities Underlying This Request

- Planning, constructing, and operating major scientific user facilities that are best in the world or state of the art to serve researchers from academia, Federal laboratories, and industry
- Acquiring best-in-the-world or state-of-the-art instrumentation for nanoscale imaging, measurement, characterization, and manipulation at university and Federal Government laboratories
- Maintaining and improving nanoscale fabrication capabilities at NNI-funded research laboratories
- Ensuring that industrial, academic, and government researchers have ready access to these world-class facilities to develop prototypical nanoscale test structures; measurement instruments; standard reference materials; and electronic, NEMS/MEMS, and biological devices critical to agency missions and to the Nation's nanotechnology needs
- Leveraging Federal Government user facilities funded outside the NNI for nanotechnology R&D, such as the X-ray, neutron, and electron scattering capabilities and characterization tools at facilities supported by DOE, NSF, and NIST
- Creating an infrastructure that facilitates use of instrumentation and equipment from distant locations—true teleoperation of advanced instrumentation for imaging, characterization, and fabrication at the nanoscale

Highlights of the 2007 Request

- Completion of the physical construction and installation of the initial suite of specialized equipment at four DOE NSRCs, and start of full operation of these major user facilities.

- Transitioning of the fifth DOE Nanoscale Science Research Centers from construction to initial operation.
- Completion of the Nanotechnology Characterization Laboratory at the National Cancer Institute (NCI).
- Full operation and expansion of facilities for conducting nanomanufacturing R&D—a major focus for this PCA in 2006 and 2007. Examples described more fully in agency activities include the new NSF Center for Hierarchical Nanomanufacturing and NIST's Center for Nanoscale Science and Technology (CNST).

Interagency Planning, Coordination, and Collaboration Supporting the 2007 Request

DOD (DTRA), DOE: Finalization by the Defense Threat Reduction Agency (DTRA) Joint Science and Technology Office for Chemical/Biological Defense of a memorandum of agreement with the Center for Integrated Nanotechnologies (CINT), a DOE NSRC national user facility managed by Sandia National Laboratories and Los Alamos National Laboratory, for collaboration on the use of CINT facilities for R&D activities.

DOD, NSF: Joint funding of Materials Research Science and Engineering Centers and of two Nanoscale Science and Engineering Centers.

DOD, DOE, NASA, NSF, NIH: Partnerships between the NCI Centers of Cancer Nanotechnology Excellence and NIH Nanomedicine Roadmap centers, initially funded in 2005, with many of the NNI infrastructure centers supported by other agencies.

These multiagency and multidiscipline collaborations among some of the most important nanotechnology resources in the nation build scientific and technical insights and enhance outcomes across the disciplines.

DOE, DOD, EPA, NASA, NSF, USDA: DOE and NSRC staff members continue to inform and encourage other agencies and their grantees about availability and use of NSRC capabilities via various mechanisms, including grantee meetings and workshops. Each NSRC is also instituting annual user meetings as it moves into full operation.

DOE, NIH, NIST, NSF: Participation in the Interagency Working Group on Neutron and Synchrotron Facilities.

DOE, NIST, NSF: Co-sponsorship of an NNI workshop on the role of X-ray and neutron facilities in nanotechnology to highlight the role of major characterization facilities that support advances in nanoscale science and technology.

NIST, NSF: Ongoing operation of the NIST Center for Neutron Research and expansion of user access to nanocharacterization tools.

NSF, NASA, DOD, DOE: Coordination of plans and activities at NSF's National Nanotechnology Infrastructure Network (NNIN) and Network for Computational Nanotechnology (NCN) with those of centers funded by DOD, NASA, and DOE.

2006 and 2007 Activities by Agency

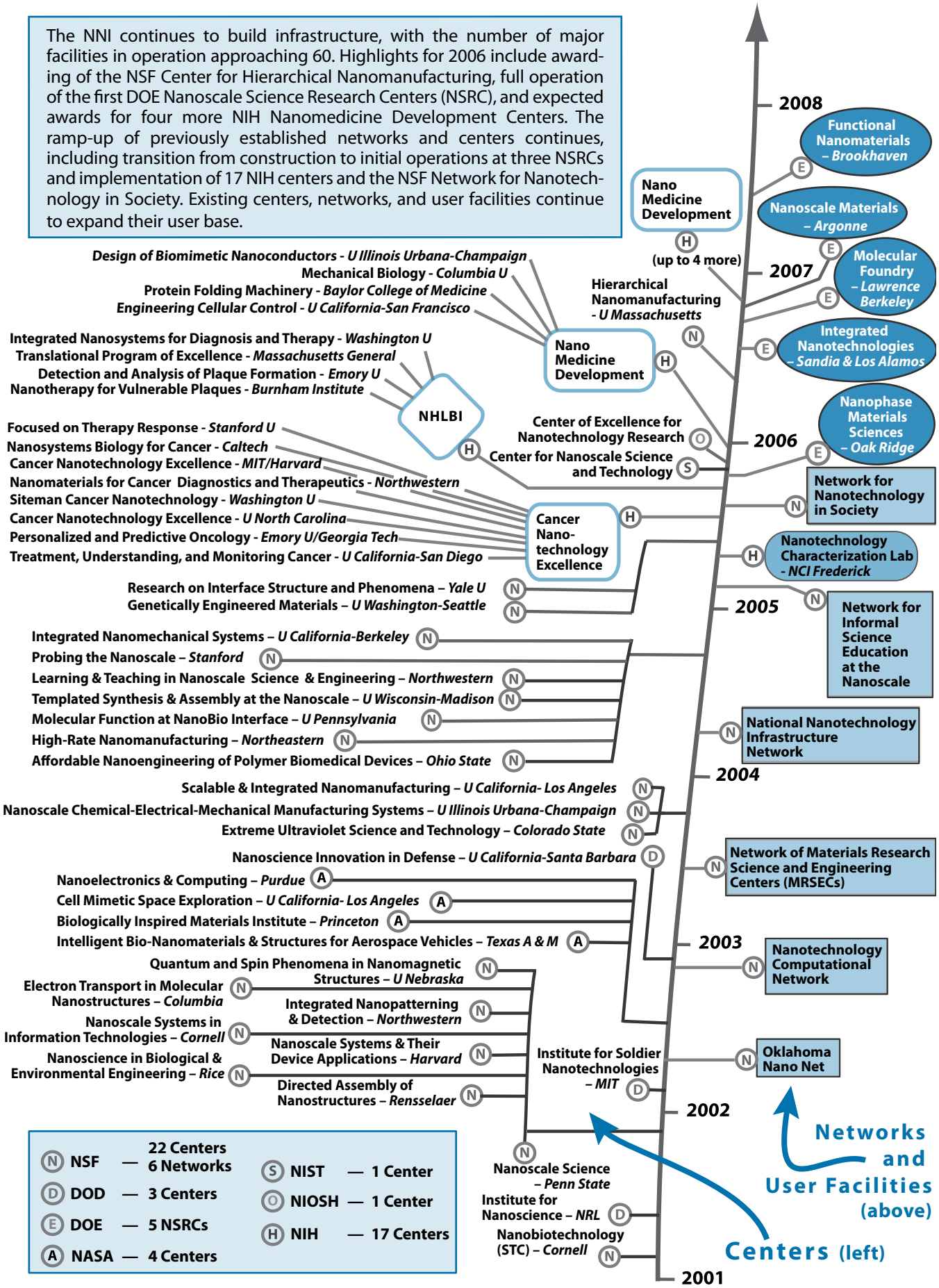
DHHS (NIH): Complete the NCI Nanotechnology Characterization Laboratory, a facility specifically aimed at providing support for the use of nanotechnology for prevention, diagnosis, and treatment of cancer.

DOC (NIST): The NIST Advanced Measurement Laboratory (AML) is open and fully functional. Over 100 experiments have been moved into the laboratory. The NIST CNST opened in 2006. Facilities of the CNST will enable fabrication of new nanoscale devices, instruments, and standards, and provide access to expensive nanofabrication tools, technologies, and expertise.

The NIST Center for Neutron Research (NCNR) is expanding access to leading neutron nanocharacterization tools and is developing new neutron diffraction and spectroscopy instrumentation that will provide unique nanoscale information. The NCNR hosts the nation's leading reactor-based neutron research facilities, offering a unique capability to probe the structure and properties of materials at the nanoscale. The NCNR, in partnership with the National Science Foundation and other agencies, operates as a national user facility to provide

Figure 1. NNI Centers, Networks, and User Facilities

The NNI continues to build infrastructure, with the number of major facilities in operation approaching 60. Highlights for 2006 include awarding of the NSF Center for Hierarchical Nanomanufacturing, full operation of the first DOE Nanoscale Science Research Centers (NSRC), and expected awards for four more NIH Nanomedicine Development Centers. The ramp-up of previously established networks and centers continues, including transition from construction to initial operations at three NSRCs and implementation of 17 NIH centers and the NSF Network for Nanotechnology in Society. Existing centers, networks, and user facilities continue to expand their user base.



the nation's only significant capabilities for cold neutron diffraction, spectroscopy, neutron trace analysis, and neutron imaging. This center presently provides over two-thirds of all neutron measurements performed in the United States. It is one of the most productive facilities of its type in the world and complements the accelerator-based neutron research facilities operated by other Federal agencies.

DOC (TA): Continue to explain and represent, as appropriate, the department's investment in nanotechnology-related facilities at NIST, including NIST's AML, which houses many of the new CNST's nanomanufacturing and nanometrology capabilities. With these capabilities, researchers will be able to fabricate prototypical nanoscale test structures, standard reference materials, and electronic devices.

DOD: Provide advanced nanoscience instrumentation via the Defense University Research Instrumentation Program (DURIP); provide DOD facilities and instrumentation capable of contributing to nanoscience research.

The 2007 DOD program includes an expected increase of approximately $21 million in this PCA in order to develop novel lithography instrumentation for affordable, high-performance, low-volume, and application-specific integrated circuits. Furthermore, this new facilities and instrumentation initiative will provide a cost-effective manufacturing technology for low volume nanoelectromechanical systems and nanophotonic devices.

DOE: Utilize the Spallation Neutron Source (SNS), located at Oak Ridge National Laboratory, to enable the next generation of materials research at the nanoscale and beyond. The successful completion of this $1.4 billion scientific user facility, which will provide the most intense pulsed neutron beams in the world, was formally certified by the Secretary of Energy in June 2006.

By or during 2007, complete installation and commissioning of the initial suite of specialized equipment for four of the five DOE Nanoscale Science Research Centers (NSRCs). These four, at Oak Ridge National Laboratory, Lawrence Berkeley National Laboratory, Sandia and Los Alamos National Laboratories, and Argonne National Laboratory, will thus move into full operations as user facilities with access provided on the basis of merit-reviewed proposals. Collectively, the NSRCs constitute the major scientific infrastructure investment under the NNI.

In conjunction with establishment of the NSRCs, novel beamlines and instrumentation specifically designed for nanoscale science are being brought online at existing collocated major scientific user facilities such as the Advanced Photon Source and National Synchrotron Light Source synchrotrons.

NSF: Continue to fund 22 centers of excellence—18 Nanoscale Science Engineering Centers and 4 new Materials Research Science and Engineering Centers established since 2001—and two major user-facility networks, the National Nanotechnology Infrastructure Network and the Network for Computational Nanotechnology. Funding provided in 2006 will bring all 20 user-facility sites (13 sites for the NNIN and seven sites for the NCN) into full operation. Based on previous history of usage, these will provide support for about 7,500 academic, industry, and government users, and industry partnerships with over 100 companies per year. The Major Research Instrumentation Program and other programs will continue to support the creation of smaller academic nanoscale science and engineering facilities.

Additionally, a new NSEC on nanomanufacturing has been established in 2006, along with mechanisms for sharing best practices in research, education, and management with the existing NSECs. The Center for Hierarchical Nanomanufacturing and the Center for Nanotechnology in Society, as well as the Center for Learning and Teaching in Nanoscale Science and Engineering (focused on grades K-16) and a Network for Informal Science Education at the Nanoscale, all have roles in disseminating information and supporting nanotechnology activities at the national level.

NSF-supported multidisciplinary user facilities for X-ray synchrotron radiation, neutron scattering, and high magnetic fields will continue to provide support to nanotechnology researchers from a broad range of disciplines, including physics, chemistry, materials research, engineering, and the biological sciences.

PCA 7: Societal Dimensions

NNI Agencies Requesting 2007 Funding for R&D Related to This PCA: *DHHS (NIH), DHHS (NIOSH), DOC (NIST), DOD, DOE, EPA, NSF, USDA (CSREES)*

Other Participating Agencies: *CPSC, DHHS (FDA), DOC (TA), DOS, ITC, ITIC, USDA (FS)*

The Societal Dimensions Program Component Area focuses on the issues of social change and safety aspects of nanotechnology, on both a domestic and global scale. This PCA encompasses three subtopics:

1. Research directed at environmental, health, and safety (EHS) impacts of nanotechnology development, and risk assessment of such impacts
2. Education-related activities such as development of materials for K-12 schools, undergraduate programs, technical training, learning in informal settings, and public outreach
3. Research directed at identifying and quantifying the broader societal aspects of nanotechnology, including economic, workforce, educational, ethical, legal, and other social implications

Developing NNI activities in these areas concurrently with the scientific research programs is essential. By doing so, the NNI facilitates public understanding of nanotechnology, is better able to proactively address public concerns and identify possible pitfalls, and can more effectively recommend approaches to optimizing the benefits of nanotechnology. Cultivating public trust through open communications, education, policy foresight, and cooperation with the international community is vital. Public awareness, acceptance of, and knowledge about nanotechnology are essential for fully realizing its potential economic and societal benefits. The need to identify and address legitimate EHS issues is equally important.

President's 2007 Request

Strategic Priorities Underlying This Request

- R&D leading to a detailed understanding of the health and safety impacts of nanotechnology for researchers, workers, consumers, and the public
- R&D leading to a detailed understanding of the environmental impacts of various applications of nanotechnology
- Efforts to protect the health and safety of warfighters, first responders, and other early adopters of nanotechnology-enabled products
- Multidisciplinary education in or relevant to nanoscale science and engineering as appropriate for audiences at all age levels, "K to gray"
- Support of education to develop solid mathematics, science, and technology skills to further advance the nanotechnology field
- Research on long-term societal, ethical, legal, and economic aspects of nanotechnology, and related public interaction and outreach
- Preparation of the nanotechnology workforce and equipping future workforce members with the necessary information and skills to work safely, responsibly, and successfully in nanotechnology-related jobs and businesses
- Efforts to ensure that stakeholders who wish to participate in public debate and decision-making have access to relevant information and education

Highlights of the 2007 Request

- Continued development of the NSF Network for Nanotechnology in Society, a network of centers and projects through which social scientists, economists, and nanotechnology researchers will address key issues relating to societal implications of nanotechnology
- Continued development of the Nanoscale Informal Science Education Network, which became operational in 2006 and is establishing an infrastructure for increasing public engagement

and understanding of nanoscience and engineering through linkages between research centers and science museums

- Development of standards for environmental and toxicological studies of engineered nanoscale materials, and a metrology infrastructure supporting these standards
- Coordination of national and international efforts aimed at responsible development of nanotechnology through organization of and participation in meetings and forums
- Ramp-up of the NSF Center for Learning and Teaching in Nanoscale Science and Engineering at Northwestern University, which will train teachers and education leaders in grades 7-16 with the aim of reaching one million students in the next five years
- Further development of assay cascades for toxicity and other characterization of an increasing number of engineered nanomaterials at the Nanotechnology Characterization Laboratory (NCL) of the National Cancer Institute (NCI)
- Use of the National Toxicology Program (NTP), a multiagency program administered by the National Institutes of Health, to study the potential toxicity of nanomaterials
- Funding of major university-based toxicity study programs at the University of Houston and the University of Rochester
- Development by NIST of relevant standards for particles, environmental, and toxicological studies, and generic infrastructural metrology to support them

Interagency Planning, Coordination, and Collaboration Supporting the 2007 Request

All NNI agencies: Exchange and coordination of information related to risk assessment of nanotechnology-enabled products through participation in the Nanotechnology Environmental and Health Implications (NEHI) Working Group of the NSET Subcommittee, currently chaired by the FDA. Twenty-four agencies and offices participate in the working group, including CPSC, DOE, DOD, EPA, FDA, ITC, NASA, NIEHS, NIOSH, NIST, NSF, OMB, OSHA, OSTP, and USDA. Development and publication of a document that identifies priority environmental, health, and safety research needed to support risk assessment of nanotechnology. The document will inform the nanotechnology community in making R&D investments in this important area and will support regulatory decision-making. The NSET Subcommittee's NEHI Working Group has obtained input from regulatory agencies on their research and information needs and has worked with industry to obtain similar information.

All NNI agencies: Addressed the NNAP's recommendation to increase the NNI's outreach to and coordination with the States by organizing and conducting a second workshop on "Regional, State, and Local Initiatives in Nanotechnology" on November 3-4, 2005. The workshop provided a forum for interchange of ideas among the leaders of regional, state, and local nanotechnology initiatives and identified means to promote continued success of those initiatives and to strengthen the role of the States in achieving NNI goals.

DHHS National Toxicology Program–FDA (NCTR), NIH (NIEHS), CDC (NIOSH)) and NIH (NCI): Development of a Memorandum of Understanding, involving the multiagency National Toxicology Program and the NCI Nanotechnology Characterization Laboratory, to do split sample analysis for methods verification and collaborative toxicology evaluations on selected nanoscale materials.

DOE, NIOSH: Collaboration through a new Interagency Agreement between NIOSH and DOE's Office of FreedomCAR and Vehicle Technologies to investigate the impact of new emission controls for nitrogen oxides and soot from diesel engines on the toxicity of emitted nanoparticles. NIOSH also is consulting on nanotechnology safety issues at the DOE Nanoscale Science Research Centers, including ideas for safe facility design and operation.

DOEd, NSF, all other NNI agencies: Coordinated development of coherent educational programs of rigorous academic and technical courses for secondary and post-secondary institutions that prepare students for careers in the nanoscience and nanotechnology fields.

EPA, NIOSH: Sponsorship of the First International Symposium on Nanotoxicology: Biomedical Aspects (Miami, FL, January 28-February 1, 2006).

EPA, NIOSH, NIH (NIEHS), NSF: EPA partnership in 2006 with NIOSH, NIEHS, and NSF on a joint interagency competitive grant solicitation, "Nanotechnology Research Grants Investigating Environmental and Human Health Effects of Manufactured Nanomaterials." These Federal agencies plan to expand their partnership to include the European Union with publication of an international joint research solicitation in 2007.

FDA, NIH (NCI), NIST: Performance of fundamental nanoparticle metrology related to characterization of nanoproducts for biomedical and nanomedicine applications.

FDA, NIH (NIEHS), NIOSH: Partnership to manage and operate the National Toxicology Program's Nanotechnology Safety Initiative, which involves the toxicological evaluations of specific engineered nanoscale materials.

FDA, NIST: Collaboration with the American Association of Physicists in Medicine for use of NIST and FDA measurement capabilities to evaluate the accuracy and precision of various bioimaging methods in use at the clinical level.

FDA, NIST: Collaboration to characterize fundamental properties of zinc oxide and titanium oxide nanoparticles commonly used in sunscreen lotions.

NIOSH, other NNI agencies: Sponsorship of the International Conference on Nanotechnology and Occupational Health: Research to Practice (Cincinnati, OH, December 3-8, 2006) and the Third International Symposium on Nanotechnology and Occupational Health (Taipei, Taiwan, fall 2007).

DOD, DOE, EPA, NASA, NIST, NIOSH, NNCO, OSTP: High-level cooperation with and support of the American National Standards Institute (ANSI) efforts on nanotechnology standardization. The Director of NNCO serves as Chair of the ANSI Technical Advisory Group to the International Organization for Standardization (ISO). Agency representatives have membership on the ANSI Technical Advisory Group and the ANSI-Nanotechnology Standards Panel. At the November 2005 meeting of the ISO Technical Committee on Nanotechnologies, the United States was designated to lead the ISO Technical Committee's Working Group on Health, Safety, and Environmental Aspects of Nanotechnologies.

NIH (NCI), NSF: Leveraging of agency strengths to build support for broad-based nanotechnology training and cross-disciplinary outreach efforts, particularly at the undergraduate level. The agencies are also actively exploring ways to expand the scope of the institutional NCI-NSF Integrative Graduate Education and Research Traineeships awards initiated in 2005 in support of nanobiotechnology training.

NIH (NCI), NIST: Nanotechnology-biology collaboration on (1) novel opto-immunoassays for probing the molecular pathology of prostate cancer, and (2) development of ultrasensitive and high-throughput phage display platforms using bio-conjugated fluorescent semiconductor nanocrystals.

NSF, all NNI agencies: Organization of meetings for NSF grantees, including a forum on education and one on EHS aspects of nanotechnology, in the Nanoscale Science and Engineering Centers (NSECs), with participation from many NSET Subcommittee member agencies.

Regulatory agencies (e.g., CPSC, EPA, FDA): Development of new technologies to evaluate pharmacological disposition of products containing engineered nanoscale materials. Training of regulatory staff members on nanotechnology to enable them to make better regulatory recommendations. Conduct internal discussions and research on applicability of existing laws and regulations to nanotechnology-enabled products and systems.

2006 and 2007 Activities by Agency

DHHS (NIH): Investigate the toxicology of engineered nanoscale materials of current or projected commercial importance under the NTP's broad-based research program to address potential human health hazards from unintentional exposure associated with the manufacture and use of engineered nanoscale materials. Three NSET agencies form the core of the NTP: NIH's National Institute of Environmental Health Sciences (NIEHS); DHHS's National Institute for Occupational Safety and Health (NIOSH); and FDA's National Center for Toxicological Research (NCTR).

In 2006 and 2007, continue to expand NTP studies focused on skin uptake, inhalation, and oral routes of exposure, specifically:

- Evaluation of the size- and composition-dependent biological disposition of nanoscale crystalline fluorescent semiconductors ("quantum dots")
- Short- and long-term studies of one or more carbon-based nanoscale materials (e.g., single- or multi-walled nanotubes, fullerenes)
- Evaluation of the role of particle core and surface composition in the possible immunotoxicity of nanoscale crystalline semiconductor materials and carbon nanoscale materials
- Phototoxicology studies of representative nanoscale metal oxide particles used in industrial settings and in consumer products (e.g., titanium dioxide)

Most of the funding for the above NTP activities is contributed by NIEHS. FDA's NCTR contributes use of the state-of-the-art capabilities of its NTP Center for Phototoxicology. Other agencies such as CPSC, EPA, and OSHA are also active participants in NTP programs, including the Nanotechnology Safety Initiative, and are intimately involved in these activities. These activities are expanding in 2006 and 2007.

NCI's Nanotechnology Characterization Laboratory (ncl.cancer.gov—described above under PCA 4, Instrumentation Research, Metrology, and Standards) provides critical infrastructure for studies supporting decision-making about the implications of nanotechnology-based products. It is developing a characterization cascade for use in preclinical evaluations of nanomaterials intended for cancer therapeutics. As part of its assay cascade and in partnership with NIST and FDA, the NCL will characterize engineered nanoscale materials' physical attributes, their *in vitro* biological properties, and their *in vivo* compatibility using animal models. The time required to characterize nanomaterials from receipt through the *in vivo* phase is anticipated to be one year. Multifunctional engineered nanoscale materials, including dendrimers, liposomes, quantum dots, metals, and carbon-based particles, will be tested to fully understand health and safety implications from the perspective of intentional exposure (i.e., medical application or delivery). In carrying out its functions, the NCL will provide a comprehensive set of baseline characterization parameters that enables nanotechnology-based strategies to rapidly transition to clinical applications. The work also will provide a framework for regulatory decisions by FDA concerning the testing and approval of nanoscale cancer diagnostics, imaging agents, and therapeutics.

NIEHS is participating in 2006 with EPA, NIOSH, and NSF in funding a joint solicitation to investigate environmental and human health effects of engineered nanoscale materials. Research areas may include the toxicology, fate, transport, transformation, bioavailability, and exposures to human and other species in natural ecosystems to engineered nanoscale materials, along with industrial ecology related to these materials.

DHHS has investments that are not included under this PCA, but that are nevertheless strongly related. Studies of biocompatibility are integral to many NIH studies supported under other PCAs. For example, research to develop new nanotechnology-based imaging agents or restorative implants routinely include animal studies on the distribution, processing, and excretion of these materials, and monitoring for adverse effects that may occur during and after treatment. Even studies to develop tools with which to study cells or to develop diagnostic devices routinely examine the interaction of cells or biological fluids with the devices. Much can be learned from these studies about biocompatibility, which is in turn related also to potential toxicity.

The NCI Alliance for Nanotechnology in Cancer is supporting the education, training, and career development of graduate, post-doctoral, and mid-career investigators for multidisciplinary nano-oncology research by providing cancer nanotechnology fellowship grants as well as partnering with NSF in support of institutionally

based awards. NCI expects to award approximately 36 new grants in this area in both 2006 and 2007. NCI also is making some programmatic investments of note in broad outreach and communication efforts via its publications and website (nano.cancer.gov) regarding nanotechnology research and development as it relates to cancer and other biomedical applications. These materials are designed to engage research communities as well as policymakers and the general public on the full spectrum of societal issues attending the development of nanobiotechnology. Finally, NCI is actively supporting environmental, health, and safety research relevant to the cancer mission, particularly through the NCL.

NIH supports training in nanobiology at a consortium of institutions in Houston, Texas through a program entitled "Training for a New Interdisciplinary Research Workforce," a component of its Roadmap Interdisciplinary Research Initiative.

NIH's National Heart, Lung, and Blood Institute Programs of Excellence in Nanotechnology (reported under PCA 3, Nanoscale Devices and Systems) also include a research training component.

DHHS (NIOSH): Support focused research on nanotechnology issues associated with worker safety and health as outlined in the NIOSH Nanotechnology Strategic Plan, available at www.cdc.gov/niosh/topics/nanotech/strat_plan.html, through intramural and extramural programs and international collaborations, including assessments of the use of nanotechnologies to increase worker safety and protect health, and through research into toxicity and other potential hazards of nanomaterials.

In 2007, NIOSH plans to:

- Continue to develop and expand partnerships and collaborations with stakeholders, including industry, other agencies, and academia, to develop risk management practices for the production and use of engineered nanomaterials, including exposure assessment strategies, engineering controls, personal protective equipment, respiratory protection, and worker training
- Develop preliminary medical endpoints for exposure to nanomaterials and conduct limited surveillance studies
- Evaluate occupational exposures to engineered nanoscale materials, addressing effective exposure control in the workplace
- Continue to maintain and update its "Approaches to Safe Nanotechnology" interactive dialogue with the scientific community and the general public online at www.cdc.gov/niosh/topics/nanotech/nano_exchange.html in coordination with other NSET Subcommittee agencies
- Continue to address critical toxicological questions by further elucidating hazards to workers in nanotechnology and by conducting focused toxicology studies on pulmonary, cardiovascular, dermal, and neural effects of single-walled and multiwalled carbon nanotubes, and metal oxide nanospheres and nanowires
- Continue to develop safe handling procedures and demonstrate the effectiveness of respirators and filtration devices
- Continue partnering with EPA and NSF to fund extramural research in the areas of environmental and occupational safety and health of nanotechnology

NIOSH interdisciplinary Nanotechnology Field Teams are conducting field studies in partnership with stakeholders to observe and assess occupational health and safety practices and control technologies in facilities where nanotechnology processes and applications are used.

DOC (NIST): Develop measurement methods for *in vitro* diagnostics and standards for advanced healthcare and therapeutics, including:

- Measuring the optical properties of nanocrystals and nanorods, which are promising materials for use as tags for biological and chemical fluorescent sensors
- Developing standards for carbon nanotube characterization and metrology
- Use of optical tweezers, ultrafast lasers, and high-resolution microspectroscopy techniques extending into the far infrared to manipulate particles and measure protein motions, the kinetics of binding and folding of single RNA molecules, and the dynamics of how motor proteins change chemical energy into physical motion at the molecular level
- Use of NIST radioactive-labeled molecules and monoclonal antibodies to investigate their application for targeting tumors in radiotherapy applications

- Developing molecular imaging and radiodiagnostic techniques, such as PET (positron emission tomography) scanning, to target specific metabolic processes
- Fabricating patterned thin films with precise geometry and volume, which can be used to determine spatial distribution of iron-containing contrast agents in MRI (magnetic resonance) imaging
- Developing calibration techniques for spatial resolution and threshold detection limits for gadolinium-containing MRI contrast agents for cancer detection
- Demonstrating use of scanning probe methods to validate the presence and characteristics of MRI contrast agents in small-animal cancer models

NIST has a substantial program to train undergraduate and graduate students and postdoctoral associates in the pursuit of future nanoscale standards and measurement techniques. NIST's training program depends on its close relationships with many prominent universities. Many of the associates in the program are from underrepresented groups and enhance the cultural diversity at NIST.

DOC (TA): Work to open new channels for public comment on nanotechnology, to expand understanding of public perceptions of nanotechnology, and to ensure the widest possible public dissemination of factual information about nanotechnology; begin efforts in collaboration with academic partners to explore business, legal, international, education, and workforce issues and challenges associated with the development and commercialization of nanotechnology; work with professional societies to identify and explore the impact of nanotechnology on the law and potential implications for Federal policy.

DOD: Assure health and safety of warfighters utilizing future nanotechnology-based applications; enable physicochemical characterization and toxicology for water, air, and space environments; sustain an investment strategy to enable a multidisciplinary education system capable of sustaining the skilled workforce needed to meet future defense needs; assess, avoid, and abate any adverse environmental or health impact from defense utilization of nanotechnology.

DOE: Support research in 2006 on fate and transport of nanoscale particles in the environment; develop informational materials on nanoscience research activities and user facilities including via a dedicated website (nano.energy.gov); and interact with public audiences (students, local communities, media, and others) as an integral part of Nanoscale Science Research Center activities. Participation is anticipated in an industry-led consortium to conduct research exploring practical aspects of reproducible nanoparticle measurement, efficacy of filters and personal protective equipment, and other precompetitive topics related to nanoparticle health and safety implications.

DOS: Continue to implement a foreign policy that seeks to facilitate the prudent development of nanotechnologies by addressing international social and political concerns through cooperation and collaboration. International cooperation on environmental, health, and safety issues can help reduce risk while realizing the benefits of technological development. Cooperation on ethical, legal, and social issues can help improve public confidence in nanotechnology, encourage free trade, and promote sustainable development through the realization of clean, efficient technologies.

EPA: Support research on the toxicology, fate, transport, transformation, bioavailability, and risk exposures of humans and other species to nanomaterials, to obtain information used in risk assessment, a central aspect of EPA's mission. Such research is aimed at understanding and addressing any potential effects of engineered nanoscale materials, the characteristics of the products made from them, or aspects of the manufacturing processes involved. With NSF, NIEHS, and NIOSH, EPA will fund appropriate research proposals from a competitive solicitation that addresses these issues. This will build on and complement twenty-six projects in these areas funded by EPA in 2004 and 2005 under a similar interagency program.

Conduct research to study nanotechnology's potential to improve environmental measurement and monitoring and its potential to enhance control and remediation technologies.

In 2006, EPA is developing a voluntary pilot program for reporting of nanomaterials manufacturing under

International Cooperation on Responsible Development of Nanotechnology

Supporting responsible development of nanotechnology is one of the four principal goals of the National Nanotechnology Initiative. Since technological innovation is a global phenomenon, the responsible development goal will be achieved most effectively through international cooperation. This will require addressing multiple factors in parallel, including: (1) commercialization of widely beneficial applications, (2) effects of innovation on the labor pool and the distribution of jobs in manufacturing and other areas, (3) equitable access to innovative technology, (4) societal changes that could result from such innovation, and (5) avoidance of potential negative impacts from new products.

The NNI and the participating agencies collaborate with their counterparts in other nations via many mechanisms, including bilateral and multilateral communication regarding governmental nanotechnology initiatives, taking part in international standards development, joint agency and individual agency support for international workshops and guest researcher programs, and direct cooperation with parallel agencies in other countries. In 2005, the NSET Subcommittee established the Global Issues in Nanotechnology (GIN) informal working group to facilitate and and coordinate NNI and other U.S. Government international activities related to nanotechnology. The GIN working group has provided interagency input at the United Nations, within the Organization for Economic Cooperation and Development (OECD), under the Wassenaar Arrangement, for bilateral meetings, and in other international forums.

Organization for Economic Cooperation and Development

With coordination by the GIN working group, the United States has played a lead role in proposing and scoping the activities for two new bodies within OECD—one in the Environmental Directorate and one in the Directorate for Science, Technology, and Industry (DSTI). These complementary bodies will provide expertise and appropriate forums for discussions on a wide range of nanotechnology-related topics that will benefit from international coordination and cooperation.

In December 2005, EPA hosted a workshop on the Safety of Manufactured Nanomaterials, under the auspices of the OECD Joint Meeting of the Chemicals Committee and the Working Party on Chemicals, Pesticides, and Biotechnology in the Environmental Directorate. This workshop led to a recommendation that the Joint Meeting should establish a new body focusing on safe use and development of nanomaterials. This new body will address nanotechnology issues within the scope of the parent bodies.

The U.S. has also proposed the formation of a nanotechnology subgroup under the DSTI Committee on Scientific and Technological Policy. The proposed body would address topics related to nanotechnology advancement and commercialization such as intellectual property rights, research infrastructure, education, and societal concerns. Its scope will be discussed at a workshop hosted by Switzerland in the summer of 2006. International cooperation in these areas will be essential in realizing the full benefits of nanotechnology.

International Standards Development

Standards for nomenclature, terminology, measurement procedures, exposure monitoring, and materials characterization are expected to play a critical role in both maximizing the benefits of nanotechnology and minimizing any potential risks—two essential aspects of responsible development. The development of widely applicable nanotechnology standards is thus an activity well suited to international cooperation.

NNI agencies are contributing to the work of U.S.-domiciled standards development organizations, including ASTM International, the Institute of Electrical and Electronics Engineers, and the National Electrical Manufacturer's Association, to develop voluntary, consensus-based nanotechnology standards for international use. In June 2004, the American National Standards Institute (ANSI) established a Nanotechnology Standards Panel (NSP) in response to a letter from the Director of the Office of Science and Technology Policy Dr. John Marburger, asking ANSI to facilitate and coordinate the United States efforts in nanotechnology standards development. Subsequently, the International Organization for Standardization (ISO) established a Nanotechnologies Technical Committee (ISO TC 229), and ANSI accredited a Technical Advisory Group (ANSI-TAG) to represent the United States on this ISO technical committee. The NNCO Director is Chair of the ANSI-TAG and served as leader of the U.S. delegation to the first two meetings of ISO TC 229, held in the United Kingdom in November 2005 and in Japan in June 2006. A third meeting of ISO TC 229 is scheduled for December 2006 in Korea.

Through the NNCO, the NSET Subcommittee and the relevant agencies provide funding to facilitate ANSI support of nanotechnology standards efforts. A number of NNI agencies are represented on the NSP and the ANSI-TAG to ISO TC 229. Further, the United States leads the ISO TC 229 Working Group on Health, Safety, and Environmental Aspects of Nanotechnologies. The United States recently submitted a non-nationalized version of the NIOSH document "Approaches to Safe Nanotechnology" (www.cdc.gov/niosh/topics/nanotech/nano_exchange.html) to the ISO Technical Committee, which approved it as a new work item. This is the first step toward the development, with input from other countries, of an ISO Technical Report on safe handling of nanomaterials, an informational document that will allow workers and researchers globally to benefit from the NNI's proactive efforts in the area of workplace safety.

the provisions of the Toxic Substances Control Act (TSCA), as a first step toward evaluating how TSCA can be applied to protection of public safety with respect to engineered nanoscale materials.

Released a draft white paper for public comment looking broadly at how various environmental statutes can and will be applied to protect public safety and the environment with respect to nanotechnology.

NSF: Provide extramural support for multiple activities addressing the benefits, risks, and other broad societal implications of nanotechnology, including:

- Basic research directed at environmental, health, and safety impacts of nanotechnology development
- Development of educational materials and curricula for schools, new teaching tools, technical training programs, and public outreach programs
- Support for participation in nanoscience/nanoengineering research by undergraduate students and high school teachers
- Graduate student assistantships and fellowships that cut across all NSF nanotechnology research programs
- Research directed at analyzing, identifying, and quantifying the societal dimensions of nanotechnology from social, behavioral, legal, ethical, and economic perspectives

Two new NSF-wide program solicitations have been issued in 2006, one focused on research (Nanoscale Science and Engineering) and another on education (Nanoscale Science and Engineering Education). In addition, awards through NSF core programs continue the expansion of broad-based support for the creation of knowledge at the nanoscale across all disciplines.

The NSECs, the Materials Research Science and Engineering Centers (MRSECs), and the National Nanotechnology Infrastructure Network (NNIN) include program components on EHS, ethical, legal, and social implications (ELSI), education, outreach, and interaction with the public. NSF will educate and train per year about 10,000 graduate and undergraduate students, postdoctoral fellows, and teachers. A Research Experience for Undergraduates program will be established on a competitive basis at NSECs and will continue at MRSECs.

Key NSF programs include:

- The NSEC entitled "Nanotechnology in Society" to provide a framework for addressing broad societal implications of nanotechnology.
- Nineteen MRSECs, including 4 of the 5 new MRSECs established in 2002 and 2005, which continue to fully or partially support education and outreach programs pertaining to nanoscale science and engineering. These programs include graduate and undergraduate training, precollege programs, and interaction with the public.
- The Nanoscale Informal Science Education (NISE) Network, which is to develop a broad net of activities for science museums around the country. Among them are:
  - Research and development on educational exhibitions, programs, and media designed to increase awareness, engagement, and understanding of nanoscale science, engineering, and technology
  - Development of a critical mass of science museums in the nation that have the expertise, resources, and desire to develop opportunities for the public to better understand the nanoscale
  - Development of relationships between nanoscience and engineering researchers and educators at institutions of formal and informal learning
- The NISE Network further contributes front-end research on public understanding of nanotechnology by conducting a comprehensive review of academic studies, evaluation reports, educational research literature, and public opinion research from the past decade about public understanding of nanotechnology. The network also will expand the knowledge base through educational research and evaluation concerning learning about the nanoscale to inform the development of materials and techniques.
- Development of an online clearinghouse for sharing information and resources for informal learning about nanoscale science and engineering.
- Use of the Nanoscale Center for Learning and Teaching to work towards increasing the capacity of secondary students to understand nanoscale science, engineering, and technology by supporting:

- Development of instructional materials with appropriate science, engineering, and technology content and based on research on learning
- Professional development of teachers with respect to relevant content and effective pedagogy
- Doctoral-level education focused on developing future leaders with expertise in introducing scientific and engineering advances into the school curriculum
- Research on learning and teaching related to the development of effective instructional materials and professional development in this area

NSF also supports extramural activities addressing the benefits, risks, and other broad societal implications of nanotechnology, including basic research directed at environmental, health, and safety impacts of nanotechnology development. NSF has funded hundreds of grants for such study and, among others, supports the following environmental centers and interdisciplinary groups concerned with research and education at the nanoscale:

- Fundamental Studies of Nanoparticles Formation in Air Pollution, Worcester Polytechnic Institute
- Center for Advanced Materials for Water Purification, University of Illinois at Urbana
- Center for Environmentally Responsible Solvents and Processes, University of North Carolina at Chapel Hill
- Center for Nanoscience in Biological and Environmental Engineering, Rice University
- Environmental Molecular Science Institute, University of Notre Dame
- Investigating Nano-carbon Particles in the Atmosphere: Formation and Transformation, University of Utah
- Nanoscale Processes in the Environment—Atmospheric Nanoparticles, Harvard University
- Nanoscale Sensing Device for Measuring the Supply of Iron to Phytoplankton in Marine Systems, University of Maine

USDA (CSREES): Develop new educational materials on nanotechnology for undergraduate students majoring in agricultural and food sciences and technology. Support and encourage education and outreach in various aspects of nanotechnology through funding mechanisms, including competitive research, SBIR, and higher education challenge grants.

USDA (FS): Present results from Forest Service nanotechnology research at national and international symposia, workshops, and industry meetings.

2. NNI Investments for 2006 and 2007

Budget Summary

The 2007 National Nanotechnology Initiative (NNI) budget request for nanotechnology R&D across the Federal Government is nearly $1.3 billion. The increase in spending for nanotechnology over the last six years (from an estimated $464 million in 2001) reflects this Administration's ongoing commitment to the NNI. This broad, coordinated, and balanced interagency investment is aimed at exploiting nanotechnology's potential to expand knowledge, strengthen the U.S. economy, support national and homeland security, and enhance the quality of life, while protecting public safety and health.

A summary of NNI investments for 2005 through 2007 is provided in Tables 2–6. Table 2 provides the 2005 actual budget, the 2006 estimated budget, and the 2007 funding request for those Federal agencies with R&D budgets dedicated to nanotechnology research and development. Tables 3 and 4 provide 2006 estimated and 2007 planned investments by program component area (PCA) for each of these agencies. Finally, Tables 5 and 6 show estimates for agency investments in the societal dimensions PCA in two subcomponents: programs that are primarily directed at environmental, health, and safety (EHS) R&D, and programs for education-related activities and research on the broad implications of nanotechnology for society, including economic, workforce, educational, ethical, and legal implications.

Table 2
NNI Budget, 2005-2007 (dollars in millions)*

	2005 Actual	2006 Estimate	2007 Request
NSF	335	344	373
DOD	352	436	345
DOE	208	207	258
DHHS (NIH)	165	172	170
DOC (NIST)	79	78	86
NASA	45	50	25
EPA	7	5	9
USDA (CSREES)	3	3	3
DHHS (NIOSH)	3	3	3
USDA/FS	0	2	2
DHS	1	2	2
DOJ	2	1	1
DOT (FHWA)	0	0.1	0.1
TOTAL**	**1,200**	**1,303**	**1,278**

* The numbers in this table have been updated slightly from those originally published in the President's 2007 Budget (www.whitehouse.gov/omb/budget/fy2007/pdf/spec.pdf, p. 52, Table 5-3), as agencies have refined their analysis and categorization of which specific R&D activities fall within the purview of the NNI.

** Totals may not add due to rounding.

Table 3
Estimated 2006 Agency Investments by Program Component Area (dollars in millions)

	Fundamental Phenomena & Processes	Nanomaterials	Nanoscale Devices & Systems	Instr. Research, Metrology, & Standards	Nano-manufacturing	Major Research Facilities & Instr. Acquisition	Societal Dimensions	NNI Total*
NSF	134.6	52.8	44.2	10.7	20.1	29.9	51.5	**343.8**
DOD	159.3	149.3	111.5	11.7	0.0	3.3	1.0	**436.2**
DOE	48.9	33.8	5.1	11.7	0.0	106.6	1.1	**207.2**
DHHS (NIH)	45.7	15.0	95.3	5.7	0.8	0.9	8.7	**172.0**
DOC (NIST)	18.5	7.2	17.5	19.2	7.8	4.9	2.4	**77.6**
NASA	11.0	18.0	20.0	0.0	1.0	0.0	0.0	**50.0**
EPA	0.2	0.2	0.2	0.0	0.0	0.0	3.9	**4.5**
USDA (CSREES)	0.4	1.0	1.7	0.0	0.1	0.0	0.1	**3.3**
DHHS (NIOSH)	0.0	0.0	0.0	0.0	0.0	0.0	3.0	**3.0**
USDA (FS)	0.2	1.0	0.2	0.5	0.2	0.0	0.0	**2.1**
DHS	0.0	0.0	1.5	0.0	0.0	0.0	0.0	**1.5**
DOJ	0.0	0.3	0.0	1.0	0.0	0.0	0.0	**1.3**
DOT (FHWA)	0.1	0.0	0.0	0.0	0.0	0.0	0.0	**0.1**
TOTAL*	**418.9**	**278.6**	**297.2**	**60.5**	**30.0**	**145.6**	**71.7**	**1,302.5**

* Totals may not add due to rounding.

Key points about the 2006 and 2007 NNI investments:

- The 2007 budget request is nearly $1.3 billion across thirteen agencies for nanotechnology R&D, an increase of 21% over the 2006 request[3].
- In 2006, estimated NNI investments will total over $1.3 billion, an 8.6% increase over the 2005 actual investment.
- The 2007 request for EHS R&D of $44.1 million is an increase of 18% over estimated 2006 investments, including almost doubling the budget for such research at EPA. This reflects the Administration's strong commitment to a balanced NNI research portfolio, including appropriate funding for research aimed at protecting human health and the environment.
- The 2007 request includes increases of $51 million for DOE, $29 million for NSF, and $8 million for NIST over estimated 2006 expenditures. These increases in nanotechnology R&D funding (collectively 14%) reflect the President's commitment to doubling funding for these agencies over the next ten years in support of the American Competitiveness Initiative.

Agencies with the largest budget requests and their areas of emphasis in 2006 and 2007:

- NSF continues its emphasis on Fundamental Nanoscale Phenomena and Processes (as shown in Table 4, a $132 million request for 2007 in PCA 1) and will support a new research focus on active nanostructures and nanosystems. NSF also continues to fund centers of excellence in nanomanufacturing, societal issues, and nanotechnology education.

3. 2006 figures from the NNI Supplement to the President's FY 2006 Budget, available at www.nano.gov/NNI_06Budget.pdf.

Table 4
Planned 2007 Agency Investments by Program Component Area (dollars in millions)

	Fundamental Phenomena & Processes	Nanomaterials	Nanoscale Devices & Systems	Instr. Research, Metrology, & Standards	Nano-manufacturing	Major Research Facilities & Instr. Acquisition	Societal Dimensions	NNI Total*
NSF	131.8	58.0	50.3	15.0	27.2	31.9	59.0	**373.2**
DOD	126.7	100.1	83.6	10.8	0.0	23.3	1.0	**345.5**
DOE	75.8	56.5	5.4	18.8	0.0	101.3	0.5	**258.3**
DHHS (NIH)	44.4	14.7	95.5	5.5	0.7	0.9	8.5	**170.2**
DOC (NIST)	20.8	6.5	13.8	25.1	11.3	6.7	2.0	**86.2**
NASA	1.0	12.0	11.0	0.0	1.0	0.0	0.0	**25.0**
EPA	0.2	0.2	0.2	0.0	0.0	0.0	8.0	**8.6**
USDA (CSREES)	0.4	1.0	1.2	0.0	0.1	0.0	0.1	**2.8**
DHHS (NIOSH)	0.0	0.0	0.0	0.0	0.0	0.0	3.0	**3.0**
USDA (FS)	0.2	1.0	0.2	0.5	0.2	0.0	0.0	**2.1**
DHS	0.0	0.0	2.0	0.0	0.0	0.0	0.0	**2.0**
DOJ	0.0	0.3	0.0	1.0	0.0	0.0	0.0	**1.3**
DOT (FHWA)	0.1	0.0	0.0	0.0	0.0	0.0	0.0	**0.1**
TOTAL*	**401.4**	**250.3**	**263.2**	**76.7**	**40.5**	**164.1**	**82.1**	**1,278.3**

* Totals may not add due to rounding.

- DOD, where program activities are aimed to discover and exploit unique phenomena at nanoscale dimensions to enable novel applications that enhance warfighter and battle systems capabilities. Continued support for nanomaterials research will enable robust incorporation and design of nanoscale phenomena and the realization of novel materials properties based on these phenomena. Added funding for nanomanufacturing research is anticipated via the Small Business Innovation Research (SBIR), Small Business Technology Transfer (STTR), and Manufacturing Technology (MANTECH) programs.

  The DOD nanotechnology investment reported in Table 2 for 2005 and 2006 includes many Congressional additions (earmarks). Normal DOD contract or grant award decisions rely on evaluation and ranking by scientific, technical, and military experts. Earmarked awards circumvent this standard competitive process and the thorough agency review that helps guarantee a coordinated R&D program. The significant presence of these earmarks in 2006 and prior years also makes it difficult to compare proposed 2007 funding levels with prior year funding.

  A complete inventory of Congressional additions to the DOD budget for nanotechnology R&D cannot be provided due to the difficulty in identifying the requirements of some earmarks and assessing their relevance to DOD nanotechnology programs. In 2006, earmarks that DOD has been able to identify as supporting nanotechnology R&D totaled approximately $130 million. The majority of the earmarks identified have been categorized as PCA 2 (Nanomaterials) or PCA 3 (Nanoscale Devices and Systems).

- DOE, where four of the five Nanoscale Science Research Centers will go into full operation in 2006, and the requested nanoscience research budget within the Office of Science will increase substantially. The Office of Fossil Energy is reporting nanotechnology research for the first time in 2006 and 2007.
- DHHS, with continued significant support for nanotechnology R&D funding, including implementing the NIH-wide Nanomedicine Roadmap Initiative, as well as complementary research initiatives at the National Cancer Institute; the National Heart, Lung, and Blood Institute; and the National Institute of Biomedical Imaging and Bioengineering. NIOSH continues its research program to address implications of nanotechnology for health and safety in the workplace.
- DOC (NIST), where investment in the agency's top priority to fully develop the Center for Nanoscale Science and Technology has contributed to a 10% increase in NIST's NNI funding request compared to 2006 estimated expenditures.

Estimates by the agencies for their investments in each PCA are based on the descriptions of the PCAs that are provided in Section 1 of this report, with additional details available in the NNI Strategic Plan (available online at nano.gov/html/about/strategicplan2004.html). The programmatic activities for each PCA, including interagency and individual agency programs for 2005 and 2006, key strategies for 2006, and highlights of new important activities, are described in Section 1.

Investments in PCA 7, Societal Dimensions

There has been considerable interest on the part of Congress, as well as various individuals and groups that are following nanotechnology, regarding the balance of investments by the NNI between R&D to realize the benefits of nanotechnology and R&D on the potential implications of nanotechnology for the environment and human health. Since the inception of the NNI, the importance of environmental, health, and safety aspects of nanotechnology has been recognized and has been an area of research.

To describe what the NNI is doing to ensure responsible development of nanotechnology, OMB has requested that all agencies provide funding estimates within the Societal Dimensions PCA for R&D on environmental, health, and safety implications of nanotechnology, based on the following definition. This definition is for the purpose of estimating funding and is not intended to be a comprehensive scientific or technical description of this topic:

> *Research and development (R&D) on the environmental, health, and safety (EHS) implications of nanotechnology includes efforts whose primary purpose is to understand and address potential risks to health and to the environment posed by this technology. Potential risks encompass those resulting from human, animal, or environmental exposure to nanoproducts—here defined as engineered nanoscale materials, nanostructured materials, or nanotechnology-based devices, and their byproducts.*

The definition of R&D for EHS implications is an intentionally restrictive definition to aid program managers in making clear decisions about which projects and efforts to include in this category. Note that the definition's key point is "efforts whose *primary* purpose is to understand potential risk." Thus, the funding indicated for EHS R&D does not include R&D within other PCAs that is highly relevant to EHS implications but not primarily directed at those implications.

For example, not included are studies of the basic mechanisms of interactions between engineered nanoscale materials and biological systems, or research to develop improved laboratory and field instrumentation for measuring the properties of engineered nanoscale materials. Work to develop an application of nanotechnology that also produces information related to potential toxicity of nanoscale components (e.g., treatments for cancer) is also not included in PCA 7. It should also be noted that R&D on EHS implications is taking place in industry, university, and government laboratories around the world. As described in several of the PCAs, the Nanoscale Science, Engineering, and Technology (NSET) Subcommittee of the National Science and Technology Council's Committee on

Technology is coordinating actively with these efforts, both nationally and internationally.

All funding in the Societal Dimensions PCA other than that for EHS implications supports research on ethical, legal, or societal issues and education-related activities. The NSET Subcommittee published a workshop report in 2005 assessing issues associated with the societal implications of nanotechnology. The NSET Subcommittee will use input from that report and additional public engagement efforts to refine the agencies' ongoing research programs in this area.

Tables 5 and 6 show the estimated 2006 and 2007 NNI funding in the EHS and non-EHS categories.

Table 5
Budget for Environmental, Health, and Safety R&D, 2005-2007
(dollars in millions)

	2005 Actual	2006 Estimate	2007 Request
NSF	20.9	22.1	25.7
DOD	1.0	1.0	1.0
DOE	0.5	0.5	0.0
DHHS (NIH)	2.7	4.5	4.6
DOC (NIST)	0.0	2.4	1.8
NASA	0.0	0.0	0.0
EPA	6.7	3.9	8.0
USDA (CSREES)	0.1	0.1	0.1
DHHS (NIOSH)	3.0	3.0	3.0
USDA (FS)	0.0	0.0	0.0
DHS	0.0	0.0	0.0
DOJ	0.0	0.0	0.0
DOT (FHWA)	0.0	0.0	0.0
TOTAL*	**34.8**	**37.5**	**44.1**

Table 6
Budget for Education and Ethical, Legal, and Other Societal Issues, 2005-2007
(dollars in millions)

	2005 Actual	2006 Estimate	2007 Request
NSF	29.1	29.4	33.4
DOD	0.0	0.0	0.0
DOE	0.0	0.5	0.5
DHHS (NIH)	4.1	4.2	3.8
DOC (NIST)	0.0	0.0	0.2
NASA	0.0	0.0	0.0
EPA	0.0	0.0	0.0
USDA (CSREES)	0.1	0.1	0.1
DHHS (NIOSH)	0.0	0.0	0.0
USDA (FS)	0.0	0.0	0.0
DHS	0.0	0.0	0.0
DOJ	0.0	0.0	0.0
DOT (FHWA)	0.0	0.0	0.0
TOTAL*	**33.3**	**34.1**	**38.0**

* Totals may not add, and do not sum to the Societal Dimensions PCA total listed in Table 2, due to rounding.

Utilization of SBIR and STTR Programs to Advance Nanotechnology

The NNI supports numerous activities designed to accelerate the transition of newly developed nanotechnologies from the laboratory to practical applications for commercial use and/or public benefit. The Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs are two of those activities. As called for by the 21st Century Nanotechnology Research and Development Act, OMB has obtained information on use of the SBIR and STTR programs in support of nanotechnology development from those agencies having SBIR and STTR programs. Note that only five NNI agencies—DOD, NSF, DHHS, DOE, and NASA—have STTR programs.

Tables 7 and 8 show 2004 and 2005 agency funding for SBIR and STTR awards for nanotechnology R&D as reported to OMB by individual NSET member agencies.

The DOD SBIR and STTR investment was generated by analyzing the entire DOD SBIR and STTR portfolios and identifying individual research efforts supporting nanotechnology research; therefore this data should be considered preliminary, since a detailed technical analysis has not been completed. NSF and EPA have chosen to designate nanotechnology-related opportunity areas for their 2006 SBIR and STTR programs. NSF's opportunity area is in nanomanufacturing as a component of an overall effort on manufacturing innovation. EPA is calling for SBIR proposals to apply nanotechnology to the areas of environmental monitoring and pollution control.

Table 7
2004 Agency SBIR and STTR Awards
(dollars in millions)

	SBIR	STTR	NNI Total
DOD	31.9	10.5	42.4
NSF	11.9	0.9	12.8
DHHS (NIH)*	9.3	2.6	11.8
DOE	6.8	2.8	9.6
NASA	7.2	0.6	7.8
EPA	0.6	n/a	0.6
USDA	0.6	n/a	0.6
DOC (NIST)	0.5	n/a	0.5
TOTAL	**68.8**	**17.4**	**86.2**

Table 8
2005 Agency SBIR and STTR Awards
(dollars in millions)

	SBIR	STTR	NNI Total
DOD	28.0	13.8	41.7
NSF	12.1	2.2	14.3
DHHS (NIH)*	11.1	5.2	16.3
DOE	7.7	0.4	8.1
NASA	6.0	0.0	6.0
EPA	1.0	n/a	1.0
USDA	0.0	n/a	0.0
DOC (NIST)	0.1	n/a	0.1
TOTAL	**65.9**	**21.5**	**87.4**

* NIH SBIR and STTR funding are included in its NNI totals.

Summary of Areas of Emphasis in 2006 and 2007

This section provides narrative descriptions of single-agency as well as multiagency nanotechnology activities with an emphasis on changes from 2006 to 2007. The descriptions do not attempt to cover the full range of ongoing activities of the agencies in support of the NNI.

Interagency Thrusts

As indicated previously, the new PCA structure described in the NNI Strategic Plan was first implemented in 2006 and underlies the most significant changes in NNI interagency budget priorities and coordination activities supported by the 2007 budget request. The NNI goals, and the PCAs that were identified in the plan as supporting those goals, provide the basis for changes in NNI interagency priorities over previous years. Examples of new and renewed interagency thrusts for 2007 reflecting the goals and PCAs set out in the NNI Strategic Plan include environmental, health, and safety research; nanomanufacturing; industry liaison in support of technology transfer and commercialization; standards development; and continued infrastructure development. Specific interagency activity highlights and areas of emphasis for 2007 are described below.

Environmental, Health, and Safety Research

EPA, NSF, NIOSH, and NIH (NIEHS) plan an expanded joint extramural research program addressing potential EHS implications of nanotechnology for human health and the environment. The National Toxicology Program's initiative to support research related to environmental and health aspects of nanotechnology will yield early results, as will NIOSH's efforts to establish "recommended practices" for safe handling of nanomaterials. The NSET Subcommittee's Nanotechnology Environment and Health Implications Working Group continues to provide a forum for coordinating this interagency thrust. NSET is seeking input from industry to provide additional perspectives. An NNI document that identifies and prioritizes nanotechnology EHS research needs is expected to be released in 2006 and will undergo modification in 2007 based on public comment.

Nanomanufacturing

Funding for NSF's Center for Hierarchical Nanomanufacturing was awarded in April 2006. The center will coordinate with other NSF nanomanufacturing centers, the complementary DOD Multidisciplinary University Research Initiative program, and the NIST Center for Nanoscale Science and Technology. The NSET Subcommittee's informal working group on nanomanufacturing will help coordinate these activities. NSET will also coordinate its activities in this area with the NSTC Interagency Working Group on Manufacturing Research and Development.

Industry Liaison in Support of Technology Transfer and Commercialization

The NSET Subcommittee will expand its activities to reach out to U.S. industry for input on research needs and to identify opportunities for technology transfer from NNI-funded research activities. It will continue its existing successful interactions with the semiconductor/electronics and chemical industries, while seeking input from additional industry sectors. NSF's "Silicon Nanoelectronics and Beyond" activity may serve as a model for future collaborations with industries such as automotive, biotechnology, food, forest products, and agriculture. The NNI agencies will continue to seek opportunities to promote commercialization of nanotechnology through their SBIR and STTR programs, as described earlier in the report. NSET's Nanotechnology Innovation and Liaison with Industry Working Group is helping to coordinate this interagency thrust.

Standards Development

The NSET Subcommittee member agencies will continue to participate in and provide financial support for the American National Standards Institute's Technical Advisory Group to the ISO Technical Committee on Nanotechnologies (TC 229). TC 229 is developing standards for terminology and nomenclature, metrology and characterization, and environmental health and safety in support of nanotechnology applications and commercialization. Particular effort is being devoted by

NSET member agencies in 2006 and 2007 to expedite this activity, which was initiated in 2004. The NNCO Director is Chair of the ANSI-accredited Technical Advisory Group (TAG) to the ISO and leads the U.S. delegation. The United States will lead the Working Group on Health, Safety, and Environmental Aspects of Nanotechnologies for the ISO Technical Committee. Participation in national standardization activities and in activities within the International Organization for Standardization will be complemented and supported by standards and metrology research funded by NIST and other NNI agencies. Of notable mention are the standardization efforts related to terminology supported by multiple agencies, and to biocompatibility standards co-sponsored by the National Cancer Institute and FDA.

Infrastructure Development

Two new NSF nanotechnology research centers awarded in 2005 will reach full operation in 2006, and the NSF Center for Hierarchical Nanomanufacturing will begin operation in 2006. NIH's network of Nanomedicine Development Centers will be expanded in 2006, and the Centers for Cancer Nanotechnology Excellence will begin full operation. New NNI user facilities also will become operational in 2006, including several DOE Nanoscale Science Research Centers. These and other new centers and user facilities will join a substantial existing network of dedicated nanotechnology centers around the country, as illustrated on page 23. The NNI-funded infrastructure is further complemented by an array of large-scale research facilities and centers not specifically dedicated to nanotechnology research, but which provide the specialized tools and expertise needed to conduct nanotechnology research. All of this is the result of a coordinated interagency strategy to provide the research infrastructure necessary for rapid advancement of nanoscale science, technology, and applications.

Interdisciplinary Research at the Intersections of Nanotechnology, Biotechnology, and Information Technology

NSF, NIH, NIST, DOD, and other agencies will seek new opportunities for synergistic research at the intersection of nanotechnology and biology. For example, in 2005 NIH initiated new research thrusts on nanotechnology for cancer detection and therapy, novel DNA sequencing technologies, and early detection and treatment of heart, lung, and blood diseases. These are expected to reach full operation in 2006. Similarly, DOD, NIST, NSF, NIH, and other agencies will increase their funding for research in nanotechnology in support of information technology (e.g., nanoscale devices yielding new paradigms for computing and data storage) and for use of advanced information technology in support of nanotechnology research (e.g., high-performance computing for modeling and simulation of nanostructured materials and devices).

Changes for Individual Agencies

DOD

Army, Navy, and Air Force investment in applied research (6.2) and advanced technology development (6.3) programs will grow in order to accelerate the transition of nanoscience research into mature nanotechnologies for use in military systems.

DOE

The DOE Office of Basic Energy Sciences will substantially increase basic research support for nanoscale phenomena and processes and nanomaterials in a broad range of energy-related topic areas, including activities related to the hydrogen economy, solar energy conversion, fundamental studies of materials at the nanoscale, and instrumentation for characterizing materials at the nanoscale. Overall funding levels for fundamental nanoscale scientific research, both at DOE National Laboratories and through grants to universities, are slated to increase considerably in 2007 over those in 2006 as part of the increased funding for physical science research under the American Competitiveness Initiative.

DOE's flagship activity in nanoscience, the five Nanoscale Science Research Centers (NSRCs), constitute the largest infrastructure investment within the NNI. All of the NSRCs are user facilities that are available to the entire R&D community, with time and staff support allocated on the basis of merit-reviewed proposals, and access provided at no cost to the users in the case of nonproprietary work intended for open publication. In 2007, construction and equipping of the NSRCs will be largely complete, and resources provided will primarily support the operation of these centers as user facilities.

EPA

EPA will continue to focus the majority of its research in 2006 and 2007 on the potential health and environmental implications of nanomaterials. EPA will increase its efforts in the area of risk assessment and risk management needs for nanomaterials. Finally, EPA will research potential nanoscale technology solutions to environmental problems.

NASA

A key thrust for NASA in 2006 is the application of nanotechnology to space exploration, in keeping with the President's Vision for Space Exploration announced in 2004. At a workshop co-sponsored by the NSET Subcommittee and NASA in 2004 on nanotechnology for space exploration, research opportunities were identified in areas such as nanomaterials, microcraft, micro/nanorobotics, nanosensors and instrumentation, nano-micro-macro integration, and astronaut health management. The forthcoming report from this workshop will help to guide the NASA nanotechnology research agenda in 2006 and beyond. Areas to be emphasized include (1) ultrahigh-strength and multifunctional materials; (2) high-density, low-power electronics; (3) ultrasmall and sensitive sensors; and (4) highly miniaturized spacecraft systems (from MEMS—microelectromechanical systems—to NEMS—nanoelectromechanical systems).

NIH

NIH's priorities for nanotechnology research continue to be creation of novel diagnostic and therapeutic approaches and devices, and development of new research capabilities to understand fundamental biomedical mechanisms. This research aims to improve the health of the population and to reduce suffering from disease and disability. There is no significant change in priorities from 2006 to 2007.

In addition to university/research institution-based basic research (e.g., unsolicited projects and the Nanoscience and Nanotechnology in Biology and Medicine Program) and an SBIR program (Bioengineering Nanotechnology Initiative, which has expanded to include STTR and continues for 2006 and 2007), the following NIH programs are continuing through 2007:

- Nanomedicine Roadmap, NIH-wide
- Programs of Excellence in Nanotechnology, National Heart Lung and Blood Institute
- Alliance for Nanotechnology in Cancer, National Cancer Institute
- National Toxicology Program on Toxicological Evaluation of Nanoscale Materials

NIOSH

In 2007, NIOSH will continue work in the areas of toxicity and worker exposure and will initiate work in the areas of population studies and applying risk assessment models to humans. NIOSH will continue to develop partnerships with stakeholders and other organizations to ensure the relevance of its research programs and to enable the translation of agency activities into appropriate workplace practices.

NIOSH formed interdisciplinary Nanotechnology Field Teams in 2006 and will be continuing to conduct field studies in partnership with stakeholders to observe and assess occupational health and safety practices and control technologies in facilities where nanotechnology processes and applications are used.

NIST

In support of the Administration's emphasis on nanotechnology and manufacturing, NIST has identified the Center for Nanoscale Science and Technology (CNST) as the top priority within the agency. The CNST leverages the new Advanced Measurement Laboratory (AML) and other metrology expertise at NIST to provide the best measurement capabilities and standards for industry, and it will focus on removing barriers to U.S. innovation in nanomanufacturing. The CNST directly addresses PCA 5 in nanomanufacturing to enable "scaled-up, reliable, cost-effective manufacturing of nanoscale materials, structures, devices, and systems" and does so by converting science into technology for manufacturing. The CNST will provide centralized access to NIST's unique nanometrology and nanofabrication resources, including the new Advanced Measurement Laboratory, by researchers from industry, academia, and government.

CNST's AML cleanroom has come online for internal research work and will soon be available for outside users. The nanometrology focus is what differentiates the CNST from other Federal Government and university

nanotechnology research facilities. The close proximity of world experts in nanometrology to the CNST is essential to the success of this facility.

Other NIST program growth in nanotechnology includes:

- The NIST Nanomanufacturing Program within the Manufacturing Engineering Laboratory, which is designed to develop and deliver timely measurements, standards, and infrastructural technologies that address identified critical needs for innovation and traceable metrology, process-control, and quality in manufacturing at the nanoscale, and which will support the CNST
- Continuation of a study of the implications of nanotechnology on the security of information technology systems
- Competence development projects in both the fate of nanoparticles in biological systems and in the development of standards for carbon nanotubes

NSF

NSF will place additional emphasis on discovery as well as the transition from discovery to technological innovation.

The NSF Nanoscale Science and Engineering Centers (NSECs) and nanotechnology-oriented Materials Research Science and Engineering Centers (MRSECs) are expanding research and education collaborations with each other and with the NSF networks for nanotechnology. The new NSF Center for Hierarchical Nanomanufacturing will join the three existing NSF nanomanufacturing centers as the heart of a national Network for Hierarchical Nanomanufacturing. The Center for Learning and Teaching in Nanoscale Science and Engineering (NCLT), the Network for Nanotechnology in Society, the National Nanotechnology Infrastructure Network (NNIN), the Network for Computational Nanotechnology, and the Nanoscale Informal Science Education Network (NISE) serve as collaborative resources on a national scale, and as clearinghouses for sharing of key results and best practices in nanoscale education and research. All 28 NSF centers and networks will be fully operational by the end of 2007, offering extensive national-level platforms for nanotechnology development including open access on a merit review basis. Research experiences for undergraduate students will expand at the NSECs. Two new MRSECs addressing fundamental research on nanoscale materials and phenomena will become fully operational in 2006. These centers will use nano-interface control and bioengineering approaches, respectively, for materials by design.

Increased NSF investment will support research and education on:

- Developing fundamental understanding and control of the physics and chemistry of collective phenomena at the nanoscale; and the synthesis, processing, and behavior of nanomaterials, including self-assembly and guided assembly.
- Active nanostructures, systems of nanosystems, and molecular nanosystems. Increased focus will be given to complex large nanosystems and to research on nanoscale devices and system architecture, and their respective fabrication.
- Increased focus on three-dimensional imaging and measurements of domains of scientific and systems engineering relevance with good time resolution.
- Converging science, engineering, and technology at the nanoscale, and in particular at the nano-biology and nano-information technology interfaces.
- Integrating nanosystems into systems of relevance in manufacturing, information systems, medicine, and the environment.
- Expanding joint research programs with NIOSH, EPA, FDA, USDA, and NIST that address societal aspects of nanotechnology.
- Providing educational programs and teaching materials at earlier stages, including for K-12 students and teachers, by using remote access to NSF educational facilities (NCLT, NISE, NNIN).
- Long-term societal dimensions of nanotechnology in society, and public interaction.
- Partnerships of academic researchers with industry, medical facilities, and States, which will be expanded and enhanced through the Grant Opportunities for Academic Liaison with Industry program and the Partnerships for Innovation program.

NSF will maintain the dedicated nanotechnology theme within its SBIR and STTR programs, first established in 2000, at a level of approximately $15 million for 2006 and 2007.

USDA

In 2006, USDA Forest Service is initiating research programs to use the intrinsic nanoscale properties of wood and similar lignocellulosic materials as starting materials for advanced nanomaterials; to use nanoprocesses to modify lignocellulosic materials; and to use nanometrology techniques to investigate the fundamental structure of wood-based materials, the ways in which they degrade, and methods for inhibiting this degradation.

In 2007, USDA Forest Service will place additional emphasis on these programs, using internal and external resources. Scientists will investigate areas of fundamental nanoscale phenomena and processes; nanomaterials; nanoscale devices and systems; and instrumentation, metrology, and standards for nanotechnology. The diverse nature of these programs will require support from many areas at the Forest Products Laboratory, Madison, Wisconsin (Wood Adhesive Science and Technology, Wood Surface Chemistry, Chemistry and Pulping, Performance Designed Composites, Analytical Chemistry and Microscopy Laboratory, Biodeterioration of Wood, and Durability and Wood Protection). Increased funding for these activities will come from shifting resources from other program areas to give a total funding of $2.1 million in 2007.

The USDA nanotechnology program portfolio in the Cooperative State Research, Education, and Extension Service (CSREES) will maintain its current programmatic directions in 2007. The program in CSREES (USDA's extramural research branch) includes research, education, and technology development through competitive research grants (USDA's National Research Initiative and SBIR programs), higher education challenge grants, formula funds, and special research grants. R&D efforts will have a central theme of exploiting the novel properties of nanoscale biological structures derived from important agricultural materials. The development of nanotechnology-based sensors for application in the food industry and agriculture is also a priority. Applications of new discoveries in nanoscale science and engineering in agriculture and food systems to further the mission and strategic goals of the agency will be emphasized in the setting of program priorities.

USPTO

The Nanotechnology Customer Partnership, through which Patent Office officials and patents stakeholders meet on a regular basis to share concerns and information related to the patenting of nanotechnology, will continue in 2006 and 2007. Ongoing activities within the partnership include specific nanotechnology-related patent examiner training and continued work on the cross-reference art collection of 263 subclasses for nanotechnology, designated Class 977 and entitled "Nanotechnology."

Appendices

Appendix A. Glossary

Act	Public Law 108-153, the 21st Century Nanotechnology Research and Development Act
Agencies	Departments, agencies, and commissions within the Executive Branch of U.S. Federal Government
AML	Advanced Measurement Laboratory (NIST)
ANSI	American National Standards Institute
ARO	Army Research Office (DOD)
BIS	Bureau of Industry and Security (DOC)
CNST	Center for Nanoscale Science and Technology (NIST)
CPSC	Consumer Product Safety Commission
CT	Committee on Technology of the NSTC
DHS	Department of Homeland Security
DHHS	Department of Health and Human Services
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOJ	Department of Justice
DOS	Department of State
DOT	Department of Transportation
DOTreas	Department of the Treasury
DTRA	Defense Threat Reduction Agency (DOD)
DURIP	Defense University Research Instrumentation Program (DOD)
EPA	Environmental Protection Agency
FDA	Food and Drug Administration (DHHS)
FHWA	Federal Highway Administration (DOT)
ITIC	Intelligence Technology Innovation Center
ISO	International Organization for Standardization
ITC	International Trade Commission
MANTECH	Manufacturing Technology (DOD program)
MEMS	Microelectromechanical systems
MURI	Multidisciplinary Research Program of the University Research Initiative (DOD program)
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-supported center)
NCTR	National Center for Toxicological Research (DHHS/FDA)
NEHI	Nanotechnology Environmental and Health Implications Working Group of the NSET Subcommittee
NEMS	Nanoelectromechanical systems
NHLBI	National Heart, Lung, and Blood Institute (DHHS/NIH)
NIBIB	National Institute of Biomedical Imaging and Bioengineering (DHHS/NIH)
NIEHS	National Institute of Environmental Health Sciences (DHHS/NIH)
NIH	National Institutes of Health (DHHS)
NIOSH	National Institute for Occupational Safety and Health (DHHS/Centers for Disease Control and Prevention)
NISE	Nanoscale Informal Science Education (NSF-supported network)
NIST	National Institute of Standards and Technology (DOC)
NNAP	National Nanotechnology Advisory Panel
NNCO	National Nanotechnology Coordination Office
NNI	National Nanotechnology Initiative
NNIN	National Nanotechnology Infrastructure Network (NSF program)
NRC	Nuclear Regulatory Commission
NSEC	Nanoscale Science and Engineering Centers (NSF program)
NSET	Nanoscale Science, Engineering, and Technology Subcommittee of the NSTC
NSF	National Science Foundation
NSP	Nanotechnology Standards Panel (ANSI)
NSRC	Nanoscale Science Research Centers (DOE program)
NSTC	National Science and Technology Council
NTP	National Toxicology Program (DHHS)
OMB	Office of Management and Budget (Executive Office of the President)
OSTP	Office of Science and Technology Policy (Executive Office of the President)
PCA	Program Component Area
PCAST	President's Council of Advisors on Science and Technology
TA	Technology Administration (DOC)
USPTO	U.S. Patent and Trademark Office (DOC)
USDA	U.S. Department of Agriculture

Appendix B. Agendas for 2005 Open Meetings of National Academies Committee to Review the NNI

Committee Members

Dr. James C. Williams - (Chair), The Ohio State University
Dr. Cherry A. Murray - (Vice Chair), Lawrence Livermore National Laboratory
Dr. A. Michael Andrews, L3 Communications Corporation
Dr. Mark J. Cardillo, The Camille and Henry Dreyfus Foundation, Inc.
Ms. Crystal M. Cunanan, IntraLens Vision
Dr. Peter H. Diamandis, Zero Gravity Corporation
Dr. Paul A. Fleury, Yale University
Dr. Paul B. Germeraad, IntellectualAssets, Inc.
Dr. Alan H. Goldstein, Alfred University
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Dr. Thomas S. Hartwick, Independent Consultant
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Rev. Richard L. Irving, Lakewood Village Community Church
Dr. Donald H. Levy, The University of Chicago
Dr. Harry A. Lipsitt, Wright State University (resigned 4/07/06)
Dr. Bettie Sue Siler Masters, University of Texas Health Science Center at San Antonio
Ms. Sonia E. Miller, Converging Technologies Bar Association
Mr. Edward K. Moran, Deloitte & Touche
Dr. David C. Mowery, University of California, Berkeley
Dr. Kathleen M. Rest, Union of Concerned Scientists
Mr. Thomas A. Saponas, Agilent Technologies (Retired)
Dr. Harvey W. Schadler, General Electric (Retired. Resigned 9/26/2005)
Dr. R. Paul Schaudies, Science Applications International Corporation
Dr. Tsung-Tsan Su, Industrial Technology Research Institute
Dr. Thomas N. Theis, IBM Thomas J. Watson Research Center
Dr. Mark E. Welland, Cambridge University (Resigned 9/1/2005)

Open Meetings

Workshop "To determine the technical feasibility of molecular self-assembly for the manufacture of materials and devices at the molecular scale"
February 9-11, 2005
2101 Constitution Ave, N.W., Washington DC

Day 1: Wednesday, 9 February 2005

I: Setting the Scene (A)

Panel participants: E. Clayton Teague, NNCO — Celia Merzbacher, NSTC

Q&A: What is the history, status, and strategy of the National Nanotechnology Initiative for "molecular manufacturing"?
What current NSET findings, funding, or plans will bear on the question of the technical feasibility of molecular self-assembly for the purposes of manufacturing?
What is the context of this study (including these workshop sessions) with respect to the needs of Congress for the required reporting?

II: Establishing a Common Language

Panel participants: John Randall, Zyvex — Ari Requicha, USC
Ned Seeman, NYU — Chris Phoenix, Center for Responsible Nanotechnology
Moderator: Alan Goldstein

Day 2: Thursday, 10 February 2005

III: Setting the Scene (B)

Panel participants: Scott Mize, Foresight Institute — Sean Murdock, NanoBusiness Alliance

Moderator: Kathleen Rest

Q&A: What is the current array of organizations or initiatives concerned with the progress of "molecular manufacturing"?
What role do businesses and other nongovernmental organizations play in this debate?

Overview presentation

K. Eric Drexler, Foresight Institute

IV: Possibilities and Limitations of Molecular Theory

Panel participants: Don Eigler, IBM — Peter Cummings, Vanderbilt Univ.
Ralph Merkle, Georgia Tech — K. Eric Drexler, Foresight Inst.

Moderator: Tom Theis

Q&A: Is it possible to organize chemical reactions on a large scale by manipulating atoms into structures?
Does theory support the stability of molecular machines?
What experimental data exists to support the theory, and what are the next steps?

V: Technology Status and Challenges

Panel participants: David Forrest, Institute for Molecular Manufacturing
Carlo Montemagno, UCLA — Christian Schafmeister, University of Pittsburgh

Q&A: What is the current state-of-the-art in "bottom-up" design?
(for example, the expansion of single-atom manipulation)
What is the current state-of-the-art in "top-down" design?
(for example, creating smaller and smaller features in electronics)
What of these (or what combination of these) has the potential to achieve "molecular manufacturing"?
What factors affect the timeline for success in bringing "bottom-up" manufacturing to reality and/or "top-down" manufacturing to the nanoscale?
What is coming next?
What technology challenges or barriers are prohibiting (molecular manufacturing) from production today?
What are some key challenges that need to be addressed?

Day 3: Friday, 11 February 2005

VI: Impacts and Implications

Panel participants: David Berube, U. South Carolina — Neil Jacobstein, Institute for Molecular Manufacturing
David Rejeski, Woodrow Wilson Int'l. Center for Scholars

Moderator: Mark Cardillo

Q&A: <u>Health and environment</u>
What are the potential positive and negative human health effects of (molecular manufacturing) considering intentional and unintentional human exposure?
What are the potential positive and negative environmental effects of (molecular manufacturing) considering intentional and unintentional environmental releases?
Do we have an "ice 9" or "Prey" problem to worry about?
<u>Economic and Societal</u>
Could (molecular manufacturing) replace manufacturing as we know it?
Could this enable wide-spread distributed manufacturing, resulting in downsizing of centralized manufacturing plants and reductions in the existing transportation infrastructure?
What would be the effects of truly distributed manufacturing, such as decentralization or de-urbanization?
What could be some of the other societal effects?

Committee Meeting: Vision for the National Nanotechnology Initiative
March 23, 2005
Room 109, 500 Fifth Street, N.W., Washington, D.C.

Overview of NNI: Status, Accomplishments, Future Goals

John H. Marburger III, Director of the Office of Science and Technology Policy (OSTP)
Mihail C. Roco, Chair of the National Science and Technology Council's Subcommittee on Nanoscale Science, Engineering, and Technology (NSET)

Charge to NRC Review Committee: Dialogue with Sponsors

Administration Perspective

Sharon L. Hays, Deputy Associate Director for Technology, OSTP

Congressional Perspective

Elizabeth Grossman and James Wilson, House Committee on Science:
Jean Toal Eisen, Senate Committee on Commerce, Science and Transportation

PCAST Review and Strategic Planning Update

Celia Merzbacher, National Science and Technology Council, OSTP

NNI Agency Overview and Perspectives

Patricia M. Dehmer, Department of Energy
Mihail C. Roco, National Science Foundation
David Stepp, Department of Defense
Jeffery A. Schloss, National Institutes of Health
Michael T. Postek, National Institute of Standards and Technology
Minoo N. Dastoor, National Aeronautics and Space Administration
Barbara Karn, Environmental Protection Agency
E. Clayton Teague, National Nanotechnology Coordination Office

Workshop: Standards, Guidelines, and Strategies for Responsible Development of Nanotechnology
March 24-25, 2005
2101 Constitution Ave., N.W., Washington, D.C.

Introductory Remarks

Jim Williams, Chair

SESSION 1: Societal Dimensions of Nanotechnology

Status of R&D, Standards, and Policy
Current Initiatives to Establish Standards, Guidelines, and Strategies

Panelists:	E. Clayton Teague, NNCO	Frances Shrotter, ANSI
	Barbara Karn, EPA	Vicki Colvin, Rice University and ANSI-NSP Co-chair
	Daniel Gamota, IEEE	
Moderator:	Bettie Sue Masters	*Rapporteur:* Maynard Holliday

SESSION 2: Biomedical and Environmental Applications and Implications

Potential Benefits and Risks to Human Health and Environment
Challenges in Protecting Public Health and Environment
Toxicology and Risk Assessment Methodologies for Nanomaterials

Moderator:	Kathleen Rest	*Rapporteur:* Tsung-Tsan Su
Panelists:	Andrew Maynard, NIOSH	Sally Tinkle, NIEHS
	Vicki Colvin, Rice University	David Warheit, DuPont

Dialogue: The Royal Society Report (via teleconference)

Panelists:	Ann Dowling, Univ. of Cambridge	Rachel Quinn, The Royal Society
	Mark E. Welland, Univ. of Cambridge	

SESSION 3: Establishing Standards and Guidelines for Responsible Economic Development

Laboratory Safety, Workplace Safety, Product Safety
Balancing Risks and Benefits
Standards and Guidelines for Industrial Needs
Q&A and Discussions

Moderator: Thomas Theis		*Rapporteur:* Paul Germeraad
Panelists:	Jack Solomon, Praxair	Carol Henry, ACCl
	Pat Picariello, ASTM-International	Stephen Harper, Intel
	Lori Perine, American Forest and Paper Association	

SESSION 4: Defensive Technologies, Human Enhancement, and Ethical Issues

Advances in Defensive Technologies and Ethical Implications
Enhanced Human Performance and Artificial Intelligence
Privacy and Civil Liberty Issues and Encryption
Q&A and Discussions

Moderator:	Alan Goldstein	*Rapporteur:* R. Paul Schaudies
Panelists:	Jack Solomon, Praxair	Carol Henry, ACCl
	William Peters, MIT	Debra Rolison, NRL
	George Khushf, U. of South Carolina	Rosalyn Berne, University of Virginia

SESSION 5: Societal Dimensions, Public Awareness, Education and Workforce Training

Risk Analysis and Risk Communication
Public Dialogue
Research Education and Training
Q&A and Discussions

Moderator:	Sonia E. Miller	*Rapporteur:* Edward Moran
Panelists:	Kristen Kulinowski, Rice University	Jane Macoubrie, North Carolina State University
	Richard Denison, Environmental Defense	Dietram A. Scheufele, University of Wisconsin, Madison

Wrap-Up: Summary, Questions, and Discussions

Brief recap of existing efforts
Range of needs for standards and guidelines in different nanotechnology sectors
Need for strategies for responsible development of nanotechnology
Role of government, academe, industries and organizations
Discussion of R&D needed to help clarify these issues

Committee Meeting and Workshop on Technology Transition and Economic Impact
27-28 June 2005
Board Room, 2101 Constitution Ave., N.W., Washington, D.C.

Monday, June 27, 2005

Session I – Panel discussion on the "state of the NNI"

Overall investment in the NNI
Top technical accomplishments
Tech transfer tracking and mechanisms
Leveraging and partnering agreements

Panelists: Mihail C. Roco, National Science and Technology Council / National Science Foundation
E. Clayton Teague, National Nanotechnology Coordination Office
Celia Merzbacher, National Science and Technology Council, Office of Science and Technology Policy
Moderator: Sonia Miller

Session II – Panel discussion on the unique nature of nanotech

Whether there is unique potential for technology applications
Whether an elongated length of development time is needed for nanotech vs. other technologies
Whether there are special EHS considerations
Whether venture capital interests and emphasis have affected nanotech
Whether there are special intellectual property considerations
Whether the interdisciplinary nature affects tech development

Panelists: Marlene Bourne, EmTech Research
Derrick Boston, Guth|Christopher, LLP
Bart F. Romanowicz, Nano Science & Technology Institute
Moderator: Paul Germeraad

Tuesday, June 28, 2005

Session III – Panel discussion on the unique impacts of nanotech on the economy

Whether nano might deserve special attention due to its invasiveness, diversity, or ubiquitousness
Whether any product or process safe/immune from nano-enhancement
Whether the factored impact on the economy is more or less than other technology
Whether nano is more or less disruptive than other technology
If people will be able to afford these new technologies
How nanotech compares structurally to biotech or infotech

Panelists: Matthew Nordan, Lux Research, Inc.
Andrew Dunn, Cientifica Ltd.
JoAnne Feeney, Punk, Ziegel & Company
Moderator: Edward Moran

Session IV – Panel discussion on the impact of NNI funding on industrial base development

Important of workforce training
Whether leveraging and partnering has worked, in various states and regions
How effective collaboration and transition methods work
What is the impact of patent class creation, standards, other structural developments

Panelists: Thomas A. Kalil, University of California, Berkeley / Center for American Progress
Sean Murdock, NanoBusiness Alliance
Moderator: Mary Good

Session V – Panel discussion on the state of technology transition to achieve government agency missions

Panelists: David Stepp, Defense (ARO, DOD)
Minoo Dastoor, Space (NASA)
Barbara Karn, Environment (EPA)
Greg Downing, Health (NIH)
Altaf Carim, Energy (DOE)
Moderator: Harvey Schadler

Committee Meeting and Workshop on Management, Impact, and Intellectual Property Rights
August 25-26, 2005
500 Fifth Street, N.W., Washington, D.C.

Thursday, August 25, 2005

Session I: Program Management of the NNI

Speakers:	E. Clayton Teague, NNCO	Kristin Bennett, DOE
	Norris Alderson, FDA	Jeffery Schloss, NIH/HGRI
Panelists:	E. Clayton Teague, NNCO	Kristin Bennett, DOE
	Norris Alderson, FDA	Jeffery Schloss, NIH/HGRI
	Irene Brahmakulam, OMB	Celia Merzbacher, OSTP
	James Murday, NRL	Michael Postek, NIST
	Mihail C. Roco, NSF and NSET	Treye Thomas, CPSC

How does the NNCO/NSET/NNI operate on a scale from management to coordination to reporting?
How are gaps and overlaps identified, and what actions are taken (if gaps or overlaps exist)? (Please cite instances [a few?] of interagency planning, coordination or communication at the more strategic level.)
Are management changes made at agencies as a result of interagency coordination? (If so, please cite instances [a few?], and describe outcomes [if any] of such changes.)
How does NNI (as a whole, and within agencies) address nano-related K-16 education, graduate education, and public education?
How does the U.S. program management compare to that in other regions: Japan, Europe, Asia, and the (rest of the world); what are the counterparts to the NNI?
A number of groundbreaking scientific/technical achievements in nanotechnology have occurred outside the U.S.; were there any structural or financial reasons why they didn't occur in the U.S.?
Were there any new interagency initiatives that have occurred in the past five years that were not initially envisioned?
Given that we are in a flat funding environment, what has been de-emphasized to make financial room for growing nanoscience and technology initiatives in your agency/program?

Friday, August 26, 2005

Session II: Scientific Impact of NNI

Speakers:	Sam Stupp, Northwestern University	Moungi Bawendi, MIT
	Ellen Williams, University of Maryland	Lou Brus, Columbia University
	Matthew Tirrell, University of California–Santa Barbara (videoconference)	
Lunch Speakers:	Les Kramer, Lockheed Martin	Ben Wang, Florida State University

Session III: Nano-Patents and Intellectual Property

Speakers:	Stephen Maebius, Foley & Lardner LLP	Bruce Kisliuk, U.S. Patent and Trademark Office

Can patents be a benchmark of nanotechnology development or progress?
Can patents be a measure of technology transfer?
What factors are considered when looking at patents and patent data as measures for the above purposes?
What can we learn by looking at nanotechnology patenting globally for trends or comparisons?
What are the benefits of a new patent nanotechnology classification at the USPTO?
How do different industries use patents and patenting, and are there any trends in this regard for nanotechnology?
How do universities/government/industry use patents and patenting differently, and are there are any trends in this regard for nanotechnology?

Appendix C. Contact List

National Science and Technology Council, Committee on Technology
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NSET Co-Chairs:	**Dr. Celia Merzbacher, Office of Science and Technology Policy and Dr. Altaf Carim, Department of Energy**
NSET Executive Secretary:	**Dr. James S. Murday, Naval Research Laboratory**

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