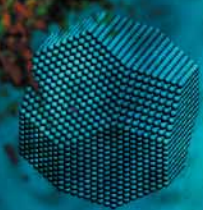
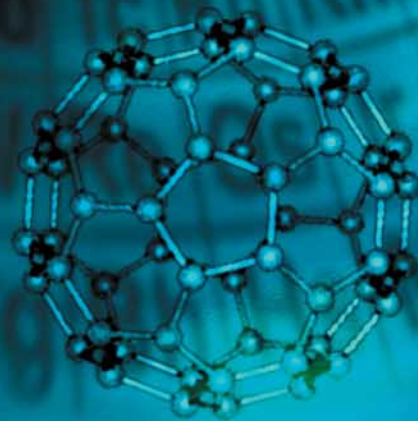


# THE NATIONAL NANOTECHNOLOGY INITIATIVE

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

Supplement to the President's FY 2006 Budget



## ***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 information technologies 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 see [http://www.ostp.gov/NSTC/html/NSTC\\_Home.html](http://www.ostp.gov/NSTC/html/NSTC_Home.html).

## ***About the Office of Science and Technology Policy***

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

## ***About this document***

This document is a supplement to the President's 2006 Budget Request submitted to Congress on February 7, 2005. It gives a description of the activities underway in 2005 and planned for 2006 by the Federal Government agencies participating in the National Nanotechnology Initiative, primarily from a programmatic and budgetary perspective. It is based on the new NNI Strategic Plan released in December 2004 and reports requested investments for 2006 by Program Component Area (PCA), as called for under the provisions of the 21st Century Nanotechnology Research and Development Act (Public Law 108-153).

## ***About the cover***

Front cover: Optical microscope image courtesy of Quantum Dot Corporation. Cellular components are labeled by five different kinds of quantum dots—fluorescing in five distinct colors—which permits concurrent tracking of five proteins within a single set of human cells. By simultaneously tracking multiple proteins, researchers can collect more detailed information on activities within the cells than can be obtained with conventional techniques. In a single, easy to see format, this image demonstrates correlations among many cellular components, rather than simply displaying the patterns one at a time. The chemistry, precise structure, and size of these nanoparticles give them their unique optical properties. Advanced biological imaging techniques can serve not only in research but also to help improve the diagnosis of cancer and other complex diseases. These quantum dot nanoparticles, developed in part with U.S. Government funding to universities and companies, are now making their way from the research labs where they were created to hospitals and medical centers for research and diagnostic medicine of the future.

## ***Cover and book design***

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# The National Nanotechnology Initiative

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



## Supplement to the President's 2006 Budget

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

March 2005

Report prepared by  
**NATIONAL SCIENCE AND TECHNOLOGY COUNCIL**  
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EXECUTIVE OFFICE OF THE PRESIDENT  
OFFICE OF SCIENCE AND TECHNOLOGY POLICY  
WASHINGTON, D.C. 20502

March 21, 2005

MEMBERS OF CONGRESS:

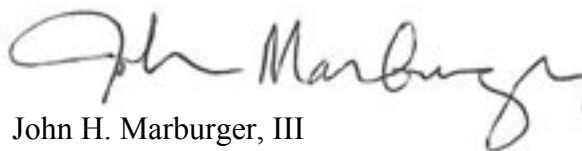
I am pleased to forward with this letter the annual report on the multi-agency National Nanotechnology Initiative (NNI) called for by the 21<sup>st</sup> Century Nanotechnology Research and Development Act of 2003 (Public Law 108-153). This Supplement to the President's 2006 Budget describes the programs and activities taking place across all 22 of the agencies that are participating today in the NNI. It is the first such report since the implementation of the updated NNI Strategic Plan in December 2004. 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 has matured considerably under the current Administration. Funding has more than doubled since the initiative was established in Fiscal Year (FY) 2001; participation has expanded from 6 to 22 agencies, 11 of which have budgets for nanotechnology R&D; and a geographically distributed infrastructure of research centers and user facilities with leading edge equipment and expertise has been put in place. In addition to supporting R&D, the NNI has developed channels for interacting with industry to facilitate the transition of research results to commercial and public benefit, and is further aiding scientific advancement and commercialization through education and workforce preparation activities.

In parallel with efforts to advance knowledge, understanding, and application of nanotechnology, the Federal Government supports a vigorous program across several agencies to understand the societal implications of nanotechnology, including potential health and environmental effects. In addition, an interagency group has been established to promote communication among the Federal agencies that support research and those with regulatory responsibilities and to identify and prioritize research needed to support the regulatory decision-making process.

As described in this report, the NNI is taking steps to leverage resources and to ensure that the Federal investment in the NNI leads to the expeditious and responsible development of nanotechnology for the Nation's benefit and in support of our continued global leadership in this important area of science and technology.

Sincerely,



John H. Marburger, III  
Director



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# Executive Summary

## Overview

The National Nanotechnology Initiative (NNI) is a multi-agency U.S. Government program aimed at accelerating the discovery, development, and deployment of nanoscale science, engineering, and technology. 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. As outlined in the recently completed NNI Strategic Plan, the NNI's goals are to maintain a world-class research and development (R&D) program; to facilitate technology transfer; to develop educational resources, a skilled workforce, and supporting research infrastructure and tools; and to support responsible development of nanotechnology. The NNI Strategic Plan also outlines seven major subject areas under which related projects are grouped, called Program Component Areas (PCAs). Investment in these PCAs is essential to achieving the NNI goals.

This Supplement to the President's 2006<sup>1</sup> Budget serves as the annual report for the NNI called for by the 21<sup>st</sup> Century Nanotechnology Research and Development Act (Public Law 108-153). The report provides details of the NNI budget for the current year (2005) and the proposed budget for 2006. The 2006 request is 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 have been addressed, a description of how the NNI participating agencies are implementing the NNI Strategic Plan, and a discussion of nanotechnology R&D funding through the Small Business Innovative Research (SBIR) and Small Business Technology Transfer (STTR) programs.

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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.

## Budget Summary

The 2006 NNI budget request for nanotechnology R&D across the Federal Government is \$1.05 billion. Estimated spending in 2005 is nearly \$1.1 billion, an increase of 9% over 2004 expenditures. The increase in spending for nanotechnology over the last five years (from an estimated \$464 million in 2001) reflects this Administration's continuing 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.

For the first time since the NNI's inception, funding has been classified by Program Component Area. 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 11 agencies with nanotechnology R&D budgets reflects a balanced strategic investment. Funding by PCA for 2006 is as follows:

1. Fundamental Nanoscale Phenomena and Processes (\$234 million)
2. Nanomaterials (\$228 million)
3. Nanoscale Devices and Systems (\$244 million)
4. Instrumentation Research, Metrology, and Standards for Nanotechnology (\$71 million)
5. Nanomanufacturing (\$47 million)
6. Major Research Facilities and Instrumentation Acquisition (\$148 million)
7. Societal Dimensions (\$82 million)

The Societal Dimensions PCA includes approximately \$39 million for programs that are directed primarily at environmental, health, and safety (EHS) R&D and \$43 million for education-related activities and research on the broad implications of nanotechnology for society, including economic, workforce, educational, ethical, and legal implications.

## Organization and Summary of the Report

- Section 1 of this report provides an overview of the NNI, including participating agencies, organization and management, and a review of the goals and priorities outlined in the updated NNI Strategic Plan released in December 2004.
- Section 2 describes the NNI R&D programs under each PCA, including specific strategic priorities, highlights of the 2006 budget request, interagency coordination activities, and a brief overview of activities underway or planned by each participating agency for 2005 and 2006.
- Section 3 provides detailed budget information by agency and PCA, and summaries of overall agency programs for 2005 and 2006. Section 3 also 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; and infrastructure development. Finally, this section provides a brief overview of agency use of the SBIR and STTR programs to achieve the goals of the initiative.

- Appendices include a glossary, a summary of responses to the 2002 National Research Council review of the NNI, and contact information for agency staff involved in the NNI.

In 2006, the NNI will continue to support a broad portfolio of R&D aimed at extending the boundaries of knowledge. As understanding of nanoscale processes and phenomena grows, greater emphasis is being placed on development of applications, especially within agencies with focused missions. In addition, funding for research into the potential environmental and health effects of nanotechnology is growing and interagency planning and coordination in this area is expanding. Programs focused on education at all levels, both in the classroom and in informal settings, are also increasing. The NNI, through the National Nanotechnology Coordination Office and other channels, plans to broaden its activities for public engagement.



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# 1. NNI Program Overview: Interagency Coordination in Support of National Priorities

## Introduction

President Bush's 2006 Budget provides over \$1 billion for the multi-agency, multidisciplinary U.S. National Nanotechnology Initiative (NNI). This program aims to accelerate the discovery, development, and deployment of nanotechnology to expand knowledge, strengthen the U.S. economy, support national and homeland security, and enhance the quality of life for all citizens. With funding for the NNI, including the 2006 request, now totaling over \$5 billion since its inception in 2001, this Administration continues to support the NNI vision of a future in which the ability to understand and control matter on the nanoscale leads to a revolutionary change in technology and industry.

The NNI investment supports a broad spectrum of research and development (R&D), including fundamental research on the unique phenomena and processes that occur at the nanometer scale, design and discovery of new nanoscale materials, and development of nanotechnology-based devices and systems. To complete the chain from discovery to commercialization, the NNI supports research on instrumentation, metrology, standards, and manufacturing at the nanoscale. Concurrent with supporting R&D aimed at advancing nanotechnology, the NNI has made responsible development of this new technology a priority through support of research on environmental, health, and safety implications and on ethical, legal, and other societal aspects of nanotechnology.

In addition to supporting R&D, the NNI provides funds for the creation of university and government facilities with the specialized instrumentation and equipment required for nanoscale R&D. The NNI also supports activities aimed at educating the nanotechnology researchers of the future and generating the workforce necessary for the growing use of nanotechnology in industry, primarily by providing funds for undergraduate, graduate, and postgraduate

training in nanotechnology-related disciplines. The NNI plays a key role in fostering cross-disciplinary interactions, and in disseminating information to participating agencies and to the public, through workshops and meetings, as well as via the Internet ([www.nano.gov](http://www.nano.gov)). Finally, the NNI encourages businesses of all sizes to exploit the opportunities offered by nanotechnology. Small businesses, which are a primary source of U.S. innovation, are encouraged to develop commercial uses of nanotechnology through the Small Business Innovative Research (SBIR) and Small Business Technology Transfer (STTR) programs.

As called for in the 21<sup>st</sup> Century Nanotechnology Research and Development Act (Public Law 108-153, hereafter referred to as "the Act"), this report describes, from a programmatic and budgetary perspective, the activities underway in 2005 and planned for 2006 by Federal agencies participating in the NNI. It also describes briefly the updated NNI Strategic Plan released in December 2004 and the restructuring of the NNI according to the new plan.

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

The Federal agencies participating in the NNI have diverse missions, but each expects to derive benefits that support its mission through enhanced capabilities or informed procedures. At the same time, the agencies expect to advance national priorities through an increased basic understanding of nanoscale phenomena and application of that understanding to the development of novel technologies.

Twenty-two Federal agencies currently participate in the NNI (Table 1), up from six at the start of the initiative. Eleven agencies now support intramural and/or extramural nanotechnology R&D programs. The remaining eleven agencies participate as partners and in-kind contributors because the development of nanotechnology is relevant to their missions or regulatory roles.

## NNI Organization and Management

The NNI is managed within the framework of the Committee on Technology of the National Science and Technology Council (NSTC). The NSTC is a Cabinet-level body and is the principal means by which the President coordinates the diverse science and technology programs across the Federal Government. The NSTC's Nanoscale Science, Engineering, and Technology (NSET) Subcommittee coordinates the plans, budgets, programs, and reviews for the NNI. The subcommittee is composed of representatives from each participating agency, the Office of Science and Technology Policy, and the Office of Management and Budget.

As the active interagency coordinating body for nanotechnology R&D, the NSET Subcommittee establishes the goals and priorities for the NNI and develops plans, including appropriate interagency activities, aimed at achieving those goals. The NSET Subcommittee promotes a balanced investment across all agencies, so as to address all of the critical elements

that will support the development and utilization of nanotechnology. The NSET Subcommittee exchanges information with academic, industry, and state and local government groups that are conducting research on and using nanotechnology. A number of working groups have been formed under the NSET Subcommittee to improve the efficiency of its operations and focus interagency attention and activity on key issues. Current working groups are focused on environmental and health implications of nanotechnology, liaison activities with industries, nanomanufacturing, and public engagement.

The National Nanotechnology Coordination Office (NNCO) provides technical and administrative support to the NSET Subcommittee and supports the subcommittee in the preparation of multi-agency planning, budget, and assessment documents. The NNCO also serves as the point of contact on Federal nanotechnology activities for government organizations, academia, industry, professional societies, foreign organizations, and others. Finally, the NNCO develops and makes available printed and other materials concerning the NNI, and maintains the NNI website, [www.nano.gov](http://www.nano.gov).

**Table 1**  
**List of Federal Agencies**  
**Participating in the NNI During 2005**

**Federal agencies with budgets dedicated to nanotechnology research and development**

Department of Agriculture (USDA)  
 Department of Defense (DOD)  
 Department of Energy (DOE)  
 Department of Homeland Security (DHS)  
 Department of Justice (DOJ)  
 Environmental Protection Agency (EPA)  
 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 State (DOS)  
 Department of Transportation (DOT)  
 Department of the Treasury (DOTreas)  
 Food and Drug Administration (FDA, Department of Health and Human Services)  
 International Trade Commission (ITC)  
 Intelligence Technology Innovation Center, representing the Intelligence Community (IC)  
 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 21<sup>st</sup> Century Nanotechnology Research and Development Act calls for a triennial external review by the National Research Council of several aspects of the National Nanotechnology Initiative, including its technical accomplishments, the appropriateness of agency funding levels, successes in technology transfer, and responsible stewardship of societal interests. As specified by the 21<sup>st</sup> Century Nanotechnology Research and Development Act, the National Nanotechnology Coordination Office has commissioned the first such review; an interim report is planned for June 2005, and a final report for early 2006.

The National Research Council reviewed the National Nanotechnology Initiative previously in 2002. The report from that study, *Small Wonders, Endless Frontiers*, included a series of ten recommendations for strengthening the initiative. These recommendations, as well as the provisions of the Act, were critical inputs to the development process for the NNI Strategic Plan, which NSET released in December 2004. Details of how the NSET Subcommittee and the research community responded to each of these recommendations in refining the structure, goals, and activities of the NNI may be found in Appendix B.

The Administration is focusing significant attention on the NNI. In order to further strengthen it, in February 2003 the President asked the President's Council of Advisors on Science and Technology (PCAST) to review key aspects of the NNI. Moreover, in July 2004 PCAST was designated as the National Nanotechnology Advisory Panel (NNAP) called for by the Act. In accordance with the terms of the legislation, PCAST, in its role as the NNAP, will have ongoing responsibilities for providing a comprehensive assessment of the NNI. The NNAP is in the process of completing its own assessment of the initiative and developing its report.

## Vision

The vision of the National Nanotechnology Initiative is a future in which the ability to understand and control matter on the nanoscale leads to a revolution in technology and industry.

Towards this vision, the NNI will expedite the discovery, development, and deployment of nanotechnology in order to achieve responsible and sustainable economic benefits, to enhance the quality of life, and to promote national security. In the process, the NNI will support the missions of the participating agencies, will ensure continuing leadership by the United States in nanoscale science, engineering, and technology, and will contribute to the nation's economic competitiveness.

## The NNI Strategic Plan

The NSET Subcommittee, with the support of the NNCO, recently published a strategic plan laying out the vision (see box above) and overarching goals for the next five to ten years of the initiative, along with a strategy and activities aimed at achieving these goals. The plan also specifies areas of investment, or Program Component Areas (PCAs). PCAs cut across the nanotechnology interests and needs of participating agencies, providing a structure for directing and coordinating the agencies' research efforts and funding.

The new strategic plan builds on the initial plans for the NNI described in *National Nanotechnology Initiative: The Initiative and Its Implementation Plan* (July 2000).<sup>2</sup>

The NSET Subcommittee developed the plan based on evaluations of the current state of nanotechnology and identification of key areas for future R&D efforts. Government, academic, and industry nanotechnology experts participated in the planning process through a series of eighteen workshops over the past two years, culminating with the September 2004 NNI Research Directions II Workshop.

2. Both documents are available from the NNI website. See [http://www.nano.gov/NNI\\_Strategic\\_Plan\\_2004.pdf](http://www.nano.gov/NNI_Strategic_Plan_2004.pdf) and <http://www.nano.gov/html/res/nni2.pdf>, respectively.

## Goals of the NNI

The NSET Subcommittee has identified four goals for the NNI. Progress toward all four is critical to achieving the vision. The goals are as follows:

1. **Maintain a world-class research and development program aimed at realizing the full potential of nanotechnology**
2. **Facilitate transfer of new technologies into products for economic growth, jobs, and other public benefit**
3. **Develop educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology**
4. **Support responsible development of nanotechnology**

The NNI Strategic Plan presents expanded descriptions of each of the goals, including examples of current activities and new strategies for continued progress and success of the NNI.

## NNI Program Component Areas

Program Component Areas are defined by the Act as major subject areas under which related NNI projects and activities are grouped. Whereas the NNI goals embody the vision of the initiative and provide structure for its strategy and plans, the PCAs represent areas of investment that are essential to accomplishing those goals. These areas cut across the interests and needs of the participating agencies, and advancement in each area may be expedited through coordination of

work by multiple agencies. The PCAs are intended to provide a means by which the NSET Subcommittee, as the interagency coordinating body, the Office of Science and Technology Policy (OSTP), the Office of Management and Budget (OMB), Congress, and others may be informed of and direct the relative investment in these key areas. The PCAs also provide a structure by which the agencies funding R&D can better direct and coordinate their activities. Agency plans for each PCA will be included in the annual NNI supplement to the President's Budget, commencing with this report for 2006. The seven PCAs are defined as follows:

**1. Fundamental nanoscale phenomena and processes**

Discovery and development of fundamental knowledge pertaining to new phenomena in the physical, biological, and engineering sciences that occur at the nanoscale. Elucidation of scientific and engineering principles related to nanoscale structures, processes, and mechanisms.

**2. Nanomaterials**

Research aimed at discovery of novel nanoscale and nanostructured materials and at a comprehensive understanding of the properties of nanomaterials (ranging across length scales, and including interface interactions). R&D leading to the ability to design and synthesize, in a controlled manner, nanostructured materials with targeted properties.

**3. Nanoscale devices and systems**

R&D that applies the principles of nanoscale science and engineering to create novel, or to improve existing, devices and systems. Includes the incorporation of nanoscale or nanostructured materials to achieve improved performance or new functionality. To meet this definition, the enabling science and technology must be at the nanoscale, but the systems and devices themselves are not restricted to that size.

**4. Instrumentation research, metrology, and standards for nanotechnology**

R&D pertaining to the tools needed to advance nanotechnology research and commercialization, including next-generation instrumentation for characterization, measurement, synthesis, and design of materials, structures, devices, and systems. Also includes R&D and other activities related

to development of standards, including standards for nomenclature, materials, characterization and testing, and manufacture.

**5. Nanomanufacturing**

R&D aimed at enabling scaled-up, reliable, cost effective manufacturing of nanoscale materials, structures, devices, and systems. Includes R&D and integration of ultra-miniaturized top-down processes and increasingly complex bottom-up or self-assembly processes.

**6. Major research facilities and instrumentation acquisition**

Establishment of user facilities, acquisition of major instrumentation, and other activities that develop, support, or enhance the Nation's scientific infrastructure for the conduct of nanoscale science, engineering, and technology research and development. Includes ongoing operation of user facilities and networks.

**7. Societal dimensions**





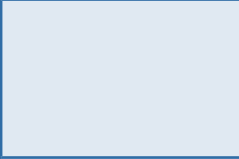

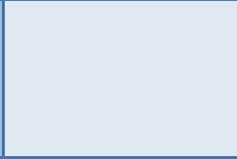

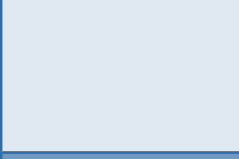
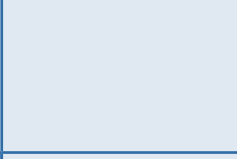
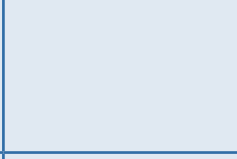


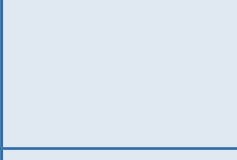
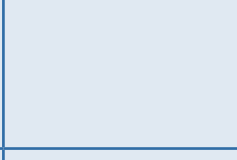
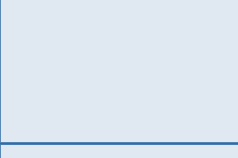

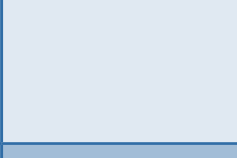
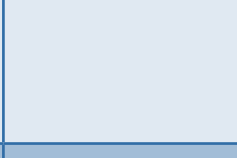
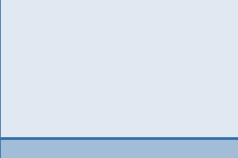







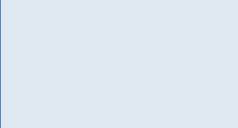
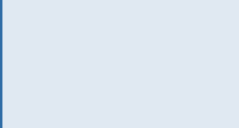


Various research and other activities that address the broad implications of nanotechnology to society, including benefits and risks, such as:

- Research directed at environmental, health, and safety implications of nanotechnology development and risk assessment of such impacts
- Education
- Research on the ethical, legal, and societal implications of nanotechnology

The relationships between the PCAs and the NNI goals are shown in Table 2. The NNI is primarily an R&D program, and therefore, not surprisingly, all the PCAs support the first NNI goal: to maintain a world-class nanotechnology R&D program. In fact, all of the PCAs are related to some extent to each of the NNI goals. Note that the activities of one or more PCAs are critical to making progress towards each goal of the NNI.



**Table 2**  
**Relationship of Program Component Areas to NNI Goals**

		Goal 1: Maintain a world-class research and development program aimed at realizing the full potential of nanotechnology	Goal 2: Facilitate transfer of new technologies into products for economic growth, jobs, and other public benefit	Goal 3: Develop educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology	Goal 4: Support responsible development of nanotechnology
Critical to Goal  Primary to Goal  Secondary to Goal 					
Program Component Areas	Fundamental Nanoscale Phenomena and Processes				
	Nanomaterials				
	Nanoscale Devices and Systems				
	Instrumentation Research, Metrology, and Standards for Nanotechnology				
	Nanomanufacturing				
	Major Research Facilities and Instrumentation Acquisition				
	Societal Dimensions				



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## 2. NNI Research by Program Component Area

**N**NI research in each PCA 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 R&D. Inclusion in the list of participating agencies indicates a significant relationship to the agency's mission, interest, or needs. Agency names have been abbreviated—see the glossary in Appendix A for the full agency names.
- A brief description of why this PCA is important for the overall vision and goals of the NNI.
- A list of long-range strategic interests underlying the 2006 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 2006 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 2006 request in the PCA.
- A concise description by agency of the major programs within the PCA, underway in 2005 and planned for 2006. This document is not intended to be a thorough overview of the full nanotechnology programs of the agencies.

### *Planning and Coordination Across PCAs*

Several NNI planning and coordination activities support all the PCAs:

- Participation in the NSET Subcommittee enables coordination of activities under all of the PCAs among the participating agencies, for example, through participation in proposal evaluations, program review, and workshop planning.
- A number of agencies with regulatory responsibilities—CPSC, EPA, FDA, NIOSH, 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, engagement in international R&D activities.
- During 2005 and 2006, agencies will develop focused and specific research targets for each of the PCAs and will form interagency collaborative projects and partnerships with industry to achieve the targets.

## Fundamental Nanoscale Phenomena And Processes

**NNI Agencies Requesting 2006 Funding for R&D Related to This PCA: DOC (NIST), DOD, DOE, EPA, HHS (NIH), NASA, NSF, USDA**

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

The overarching aim of coordinated NNI funding for this PCA 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 understanding and discovery 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 2006 Request

#### *Strategic Priorities Underlying This Request*

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

- 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
- 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 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 photoelectric cells, and in combination with surface effects for application in unique catalysts

#### *Highlights of the 2006 Request*

- 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
- Research on molecular motors to provide a window on nanoscale phenomena and processes involved in bottom-up assembly approaches

#### *Interagency Planning, Coordination, and Collaboration Supporting the 2006 Request*

**DOD, NASA, NSF:** Coordinated efforts on modeling and simulation for nanoscale processes and phenomena.

**EPA, NASA:** Joint collaboration to develop a testing technique and methodology for the identification, characterization, and correlation of carbon nanotubes and combustion processes.

**NIH:** The Nanomedicine Roadmap Initiative and two nanoscience and nanotechnology program announcements (including one for SBIR) are activities coordinated across a number of the institutes and centers of the NIH.

#### **USDA, other NSET Subcommittee agencies:**

Investigation of the mechanisms and methods for building functional interfaces between biological and inorganic materials.

### 2005 and 2006 Activities by Agency

**DOD:** 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 catalysts, scavengers, taggants and sensors; 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:** Continue support of fundamental scientific research into nanoscale phenomena via grant programs and DOE National Laboratory research efforts. Research includes 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.

**EPA:** Research the apportionment of atmospheric particulate matter to combustion source emissions using high-resolution electron microscopy (HREM) and study nanostructures that are stable components of the particulate matter, e.g., carbon nanotubes. During 2005 and 2006, EPA plans to refine this approach to further characterize structures 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 spaceship environmental monitoring. For long-term research, the goal is to capitalize on Nature's model for the management of

information, achieving emergent complex functionality through the self-organization of a large number of primitive information inputs.

**NIH:** Use novel tools and concepts emerging from nanotechnology to improve our 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 re-classified most of its basic research portfolio as nanotechnology. Projects are classified as nanotechnology only when: nanotechnology tools and concepts are used to study biology; proposals are made to engineer biological molecules toward functions very different from those they have in nature; or they involve manipulation of biological systems by methods more precise than can be done 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 will fund 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.

Other NIH programs related to this PCA include: (a) the National Institute of General Medical Sciences (NIGMS) program area entitled, "Single Molecule Biophysics and Nanoscience," (b) a portion of the National Heart, Lung and Blood Institute (NHLBI) and National Cancer Institute (NCI) programs (with the majority of funding under the PCA on Nanoscale Devices and Systems), and (c) a portion of the National Human Genome Research Institute (NHGRI) 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.

**NIST:** Measure 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. Develop quantum-based standards and measurement techniques for industrial applications.

**NSF:** Support single investigator R&D, interdisciplinary research and education teams, national science and engineering centers, and exploratory research. Special emphasis will be placed on the following areas:

- *Novel phenomena, quantum control and basic engineering processes.* Discover and understand phenomena and design processes specific to the nanoscale, including new phenomena in mechanics, chemistry, biology, electronics, and optics. Potential applications include new devices and processes for advanced communications and information technologies such as quantum computing.
- *Biosystems at the nanoscale.* Study of biologically based or inspired systems that exhibit novel properties. Potential applications include improved drug delivery; biocompatible nanostructured materials for implantation; exploiting functions of cellular organelles; devices for research in genomics, proteomics and cell biology; and nanoscale sensory systems such as miniature sensors for early detection of cancer.
- *Multi-disciplinary research aimed at the nano-biology and nano-information interface.* Multidisciplinary research at the intersection of nanotechnology with information technology, biology, and social sciences will invigorate discoveries and innovation relevant to almost all areas of the economy.
- *Multi-scale, multi-phenomena theory, modeling, and simulation at the nanoscale.* Support large-scale computer simulation and creation of new design tools and infrastructure in order to understand, control and accelerate development in new nanoscale regimes and systems. Research in this area will focus on theory, mathematical methods, modeling and simulation of physical, chemical and biological systems at the nanoscale. The research will employ techniques from quantum mechanics and quantum

chemistry, multi-particle simulation, molecular simulation, granular and continuum-based models, stochastic methods, and nanomechanics.

**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.

**USDA:** 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, improve environmental quality, enhance production and process efficiency, and promote human health through optimal food, nutrition, and diet.

**USPTO:** Pursue efforts in the following areas:<sup>3</sup>

- Nanotechnology Customer Partnership. Objectives of the partnership 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.
- Work on new cross-reference digest for nanotechnology designated Class 977/Dig.1, entitled “Nanotechnology.” Appropriate classification will allow examiners to more easily locate relevant technical information, thereby improving patent quality.
- Continue 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.

3. These efforts have relevance to all of the PCAs.

## Nanomaterials

**NNI Agencies Requesting 2006 Funding for R&D Related to This PCA:** *DOC (NIST), DOD, DOE, HHS (NIH), NASA, NSF, USDA*

**Other Participating Agencies:** *CPSC, DOC (BIS), DOC (TA), DOC (USPTO), DOT, DOTreas, EPA, HHS (FDA), HHS (NIOSH), IC, ITC*

Nanomaterials currently represents one of the most promising arenas for early commercial nanotechnology success, as well as being an enabling technology for subsequent development of other areas of nanotechnology. There will be limited applications where freestanding nanostructures provide the solution. Obtaining a fundamental understanding of the behavior of hierarchically structured nanomaterials—a major component of this PCA—will underpin their cost-effective design and manufacture. Examples of benefits include: metals with augmented mechanical properties and lower corrosion susceptibility; ceramics that are cheaper to manufacture and that have more forgiving failure modes; and composites with multifunctional capabilities enabled by the design freedom offered by hierarchical structures.

### President's 2006 Request

#### *Strategic Priorities Underlying This Request*

Nanomaterials R&D has been a priority area for NNI research funding from the inception of the initiative. Based on results from NNI workshops and consultation with representatives from industry, subtopics that will receive particular emphasis include the following:

- 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, and controlled delivery and release of therapeutic agents
  - 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 measurements and standards for nanomaterials that will provide the critical infrastructure for manufacturing and commercialization of nanotechnology
  - 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; development of value-added novel materials and products to benefit agriculture and society

#### *Highlights of the 2006 Request*

- Basic nanomaterials research for the hydrogen economy.
- Funding to accelerate 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.
- Development of new tools for investigation of nanoscale features.
- Research on emerging properties of materials and hierarchical assembly of functional nanostructures from the molecular scale. A focus of this research will be nanostructured catalysts, as recommended by a recent NSF workshop.

- Increased research on characterization of novel properties of nanoscale structures, and on materials of agricultural and biological origins.

*Interagency Planning, Coordination, and Collaboration Supporting the 2006 Request*

**All NNI agencies:** Coordination, through the NSET Subcommittee, of all agencies' research funding, industry interactions, and workshop support in the area of nanomaterials. For example, the report from the Vision 2020 "Nanomaterials by Design" workshop and a forthcoming report from an NSET Subcommittee-sponsored workshop on that topic will provide guidance to agencies in formulating their nanomaterials research programs.

**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.

**DOD, NIH:** Synthesis of nanometer-scale materials with an optical response tunable from visible to infrared wavelengths, enabling (via joint support from DOD and NIH) R&D on non-invasive destruction of tumors in mice; initial studies have shown 100% success.

**EPA, DOE:** Further development of a novel, inexpensive sorbent to remove mercury from the emissions from coal-fired power plants. Following successful bench-scale testing of the technology in 2004, further testing is planned in 2005 and 2006.

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

**NIST, NASA:** Collaboration to develop measurement protocols for nanotubes and other nanoscale materials, including the dispersion of nanoparticles in materials for use in outer space, in an effort to greatly improve their weathering performance.

**NIST, DHS:** Application of carbon nanotubes for improved fire resistance of construction materials. Efficacy of semiconductor nanoparticles deposited on the surface of construction materials for deactivating

biological agents and for decomposing hazardous chemicals.

**NIOSH (with all other NNI agencies):** Coordination among NSET Subcommittee agencies in preparing guidance for the research community, industry, and the public on appropriate practices and strategies for safe handling of nanomaterials.

**DOC (TA and BIS) and other NNI agencies:** Support for the work of the Nanotechnology Working Group under the President's Export Council/Subcommittee on Export Administration to maximize the economic potential of nanomaterials while simultaneously protecting the security interests of the United States.

**2005 and 2006 Activities by Agency**

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

**DOE:** Research 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; and functionalized nanostructures and nanotubes.

**EPA:** In 2005, test (in a larger-scale laboratory) sorbents designed to remove mercury from coal-fired power plants. In 2006, depending on the results of the pilot-scale studies, conduct additional performance studies necessary for future full-scale testing and implementation of this technology at a commercial coal-fired power plant.



**NASA:** Research into nanomaterials with properties desired for future space systems, including large size per mass (for ultra-large 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, nano-macro structure development mechanisms; (c) integration of physical and chemical forces with external fields to get desired properties during processing as well as develop 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.

**NIH:** Research 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. Construct “smart” multifunctional particles to target specific cells or tissues, sense medically-relevant physiological or molecular signals, and 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 NCI’s Nanotechnology Characterization Laboratory (further described under the PCA on Instrumentation Research, Metrology and Standards), develop a characterization cascade for use in preclinical evaluations of nanomaterials intended for cancer therapeutics.

**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 multi-photon luminescence spectroscopy and refractive index measurements of III-nitrides 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 microscopy, chemical

sensors, and polymer nanocomposites to enhance physical and fire resistance performance of polymeric materials. Characterizing material properties for nanoimprint lithography is also a growing area within NIST.

**NSF:** Research aimed at discovery of novel nanoscale and nanostructured materials and at a comprehensive understanding of the properties of nanomaterials (ranging across length scales, and including interface interactions). Controlled design and synthesis of nanostructured materials with targeted properties, including ceramic, metallic, polymeric and composite materials. Examples of applications that could benefit from this basic nanomaterials research include molecular electronics, nanostructured catalysts, thermal processes in nanostructures, advanced drugs, quantum computing, high capacity computer memory chips, two- and three-dimensional “designed” nanostructures, biophotonics, and control of surface processes and lubrication. Five new Materials Research Science and Engineering Centers (MRSECs) awarded since the inception of the NNI continue to focus on nanomaterials research.

**USDA:** Research in the following major research 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).

**USPTO:** Support the high level of commercial patenting activity in nanomaterials as described in the section on the Fundamental Nanoscale Phenomena and Processes PCA.

## Nanoscale Devices And Systems

**NNI Agencies Requesting 2006 Funding for R&D Related to This PCA:** *DHS, DOC (NIST), DOD, DOE, EPA, HHS (NIH), NASA, NSF, USDA*

**Other Participating Agencies:** *CPSC, DOC (BIS), DOC (IA), DOC (USPTO), DOJ, DOT, DOTreas, HHS (FDA), IC, ITC, NRC*

This PCA focuses on the applied research and development needed to transition rapidly into technology the multitude of science 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 a foundation of 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 2006 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. Strategic priorities underlying this PCA include the following:

- Accelerating the transition of science discovery into practical technologies for both civilian and defense applications
- Developing an improved knowledge base of information on chemical and biological properties of nanoscale devices and systems to evaluate their uses for improving the environment and human health, and to mitigate any possible adverse implications
- Incorporating new fundamental knowledge about nanoscience and nanotechnology into systems and devices for the diagnosis and treatment of diseases
- Designing and developing active nanostructures, systems of nanosystems, and molecular nanosystems
- Creating scientific and engineering platforms—engineered materials systems or software used as a stage or scaffolding that serve as the base for generic classes of experiments—as a mechanism to facilitate exploration of innovations
- Using nanotechnology fabrication and measurement capabilities to support development of new devices for metrological applications
- Developing devices and systems based on research at the nano-biology interface and nano-information interface
- Investigating the potential for quantum physics to revolutionize information science
- Developing new nanodevices (such as Si-based quantum devices, molecular electronics, spintronics, opto-electronics, and organic thin-film transistors) to supplement and/or supplant conventional complementary metal oxide semiconductor (CMOS) devices that are currently used by the semiconductor industry
- Supporting 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
- Developing biomimetic devices for better understanding of biological structures and processes important to agricultural production, food quality and safety, human health, and environmental quality

#### *Highlights of the 2006 Request*

- R&D focused on the theme, “Silicon Nanoelectronics and Beyond,” including evaluation and review with input from the semiconductor electronics industry

- ❑ Continued growth of nanodevice research in the “base” programs of appropriate agencies, e.g., exploratory research on replacing electron charge as the information medium with electron spin, electron phase, or molecular state
- ❑ Establishing and expanding centers for application of nanotechnology to the diagnosis and treatment of cancer and of heart, lung, blood, and sleep disorders
- ❑ Thrusts in R&D on nanosystem architecture and new nanoscale-based principles for sensors
- ❑ Intensified efforts to develop a variety of mission-specific nanoscale devices described below (see “2005 and 2006 Activities by Agency”)
- ❑ Accelerated research and development on novel nanoscale sensors for defense, homeland security, agricultural, and industrial applications, such as nano-barcodes and nano-based devices for product identity preservation and tracking
- ❑ Research on controlled delivery and release of functional micronutrients and bioactive compounds to improve human health

#### *Interagency Planning, Coordination, and Collaboration Supporting the 2006 Request*

**All NNI agencies:** Forthcoming NSET Subcommittee-sponsored workshop reports on “nanobiotechnology,” “silicon nanoelectronics and beyond,” and “nano-electronics, -magnetics, and -photonics” will provide guidance to agencies in formulating their nanodevice and nanosystems research programs.

**All NNI agencies:** Coordinated approaches to regulation of nanotechnology-enabled devices and products through participation in the Nanoscale Environment and Health Implications (NEHI) Working Group of the NSET Subcommittee.

**DOD, NASA, NSF, DOE:** Cooperative efforts on modeling and simulation for nanoelectronics. Advanced simulation software developed by DOD (ARO) is now being used in collaboration with DOE (Sandia National Laboratory) to design terahertz photoconductivity experiments on nanoscale detectors.

**DOD, NASA:** Joint participation in workshop associated with the Nanomaterials for Defense Applications Conference.

**DOD, NIST:** ARO continues to manage a major program in quantum computing in coordination with the Defense Advanced Research Projects Agency (DARPA) and other agencies. Much of the work involves groundbreaking advances in nanotechnology required to sustain the fragile quantum coherent states and interactions within and among qubits. NIST plays a leadership role in the interagency Quantum Information Science Coordinating Group (QISCOG), coordinates nanoelectronics research with the Office of Naval Research, and coordinates quantum information science research with DARPA and other agencies.

**DOD, NIST:** Experimental characterization studies conducted at Yale University for DOD (ARO) are enabling NIST to optimize nanopore device fabrication.

**EPA, DOE, USDA:** In 2004, EPA collaborated with the USDA and DOE in the area of pervaporation, specifically membranes constructed of a polymer-zeolite matrix where the zeolites have nanoscale pores. EPA plans to continue these partnerships through 2005 and 2006.

**NIST, NIH:** Development of carbon nanotube chemical probes for elucidating nanochemical structures within molecular networks.

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

**USDA (with other NNI agencies):** Developing a better understanding of nano-based sensor technologies.

#### **2005 and 2006 Activities by Agency**

**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). Develop high energy density capacitors, fuel cell catalysts, and electrode structures. Engage the DOD applied research and development communities to accelerate the transition of science discovery into DOD relevant technologies: examine future platform opportunities and requirements with the Director, Defense Research and Engineering (DDR&E) Advisory Group on Electron Devices (AGED); U.S. Navy groups developing technology plans for Navy Carrier Technology (CARTECH), Navy Submarine Technology (SUBTECH), and Navy Surface Technology (SURFTECH) programs; the Air Force Future Technology Branch; and the U.S. Army Research, Development and Engineering Command (RDECOM) Nanotechnology Working Group.

**DOE:** Conduct research on electronic, magnetic, and optical properties of nanostructures, including quantum dots, nanoscale particulate assemblies, and lithographically produced nanoarrays. Research on confinement effects in nanoscale and molecular devices and on contacts and interfaces. Development of novel sensor concepts and lab-on-a-chip systems, and integration of nanoscale devices and components.

**EPA:** Support research on pervaporation membranes constructed of a polymer-zeolite matrix with nanoscale pores for use in the recovery of biofuels (such as ethanol) from process waste streams. In 2005, EPA is partnering with USDA to develop high-performance membranes and conduct bench-scale testing of this technology. In 2006, the agencies will perform pilot scale studies and work to transfer the technology to larger-scale private enterprises. Also in 2005, EPA continues its relationship with DOE to test these types of membranes under real-world conditions, including the use of actual biomass waste streams from partners' facilities. In 2006, EPA will work with DOE to extend testing to pilot scale levels.

Research also includes support for small businesses to develop nanoscale technologies and instruments for sensing, treatment, remediation, and prevention. 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.

**FDA:** Form a NanoTechnology Interest Group (NTIG), with representatives from all the FDA centers covering various categories of product areas, to ensure effective communication among the product specialists. Establish and maintain a website ([www.fda.gov/nanotechnology/](http://www.fda.gov/nanotechnology/)) to explain FDA's approach to reviewing nanotechnology-enabled products.

**NASA:** R&D for nanoscale sensors and instrumentation that enhance remote sensing, vehicle health and performance monitoring, astrobiological and geochemical research, and manned space flight.

Research on properties of structures that are not only determined 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.

**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 undesired side-effects; monitoring of treatment efficacy; and repair of tissue that is damaged due to inborn conditions and trauma (e.g., accidents, disease, environment).

For example, at the National Institute of Neurological Disease and Stroke (NINDS), 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.

At the NHLBI, 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.

Beginning in 2005, the NCI Alliance for Nanotechnology in Cancer will fund Centers for Cancer Nanotechnology Excellence (CCNEs) that will serve as hubs to develop and apply nanotechnology devices and systems to the diagnosis, prevention, and treatment of cancer; multidisciplinary cancer nanotechnology research teams; and individual projects for diagnosis, treatment, and prevention. These new activities will be integrated with existing NCI programs.

At the National Human Genome Research Institute (NHGRI), the “\$1000 Genome” program, initiated in 2004 and continuing in 2005 and 2006, explores the development of nanosensors the size of individual DNA molecules to sequence DNA rapidly and inexpensively.

**NIST:** Additional funding by NIST: (a) to intensify a new effort to develop mode-locked quantum-dot diode lasers as an inexpensive, efficient, robust and compact technology for producing fast (~20 femtosecond) optical pulses; (b) for metrology and applications of semiconductor nanowires, including development of electrically addressable nanowire lasers for homeland security and biomedical applications including nanoparticle based drug delivery systems; and (c) to accelerate development of a radio-frequency version of the single-electron transistor (rf-SET) enabling fast, local probing of nanoelectronic devices.

Perfecting a quantum-based arbitrary waveform generator to become an ac voltage standard, using nanoscale devices fabricated in-house. Arrays of single electron tunneling junctions for use as a capacitance standard. Development of other devices for quantum computing, quantum communications, microcalorimeters for materials analysis of nanoscale contaminants in semiconductor manufacturing, and arrays of microcalorimeters for infrared astronomical observations. Multi-laboratory program to develop a measurement platform for single molecule manipulation and measurements. Metrology for electrical, optical, and dimensional measurements of carbon nanotubes in

support of their use as device components. New carbon nanotube based optical coatings for thermal detectors used in laser power and energy measurement standards. Research on theoretical underpinnings of practical quantum computing devices.

**NSF:** R&D that applies the principles of nanoscale science and engineering to create novel, or improve existing, devices and systems. Incorporation of nanoscale or nanostructured materials to achieve improved performance or new functionality. Development of new concepts to understand interactions among nanoscale devices in complex systems, including the physical, chemical, and biological interactions between nanostructures and device components. Interdisciplinary research on methods for design of systems composed of nanodevices, including use of multiple layers of abstractions with various mathematical models representing component behavior in different layers. Development of: (a) new tools for sensing, assembling, processing, manipulating, controlling, and testing of nanostructures and devices; (b) techniques for manufacturing and device integration from nanoscale to macroscale; (c) design and architecture concepts; (d) specialized software for nanosystems; and (e) design automation tools for assembling systems of large numbers of heterogeneous nanocomponents including fluidics and robotics. Focused research on both advanced silicon nanotechnology devices and on post-CMOS electronic, magnetic, and optical devices: research exploring the ultimate limits to scaling of features and examining alternative physical principles for devices employed in sensing, storage, communication, and computation, including biological, molecular, and other emerging areas of electronics at the nanoscale.

**Regulatory Agencies (e.g., CPSC, EPA, FDA):**

Training of regulatory staff members on nanotechnology to enable them to make better regulatory recommendations; internal discussions and research on applicability of existing laws and regulations to nanotechnology-enabled products and systems.

**TA:** Continue to monitor developments in nanoscale devices and systems and facilitate dialogue between industry, government, and academic research communities to accelerate their commercialization.

**USDA:** Development of new sensors for improving agricultural production, enhancing food quality and safety, improving human health through optimal nutrition, and monitoring and improving environmental quality.

**USPTO:** USPTO's activities designed to support the high level of commercial patenting activity in nanoscale devices and systems are described in the section on the Fundamental Nanoscale Phenomena and Processes PCA.

## Instrumentation Research, Metrology, and Standards For Nanotechnology

**NNI Agencies Requesting 2006 Funding for R&D Related to This PCA:** *DOC (NIST), DOD, DOE, HHS (NIH), NSF*

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

Instrumentation, metrology, and standards are key links in the chain from discovery to commercialization. This PCA 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. By supporting scientific instrument development, it enables new investigations that were previously not possible and may open up entire new fields of scientific inquiry.

Today's suite of metrology tools has enabled significant exploratory nanoscale research, but the limits of their resolution and accuracy are being approached. While these tools will continue to evolve, they are not expected to meet all the future metrology requirements of nanoscale researchers. Instrumentation to probe the nanoscale requires revolutionary developments rather than just evolutionary advances 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, and ultimately in manufacturing new nanoscale products.

### President's 2006 Request

#### *Strategic Priorities Underlying This Request*

To meet the emerging needs of the nanotechnology industry, the NNI's investment strategy for this PCA will

balance 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 quantum advances in spatial and temporal 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.
- Development of nomenclature to define the growing number of nanostructures. This nomenclature should be succinct, precise, and 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 and verification of advanced simulation, visualization, and data analysis techniques and supporting standards.

*Highlights of the 2006 Request*

- 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.
- Strong advocacy for and participation by NSET Subcommittee members in the American National Standards Institute's Nanotechnology Standards Panel (ANSI-NSP) efforts to develop common nomenclature and other standards in support of nanotechnology applications and commercialization. Four areas have been identified by ANSI-NSP for standardization: (1) general terminology for nanoscience and technology, (2) systematic terminology for materials composition and features, (3) toxicity effects and environmental impact/risk assessment, and (4) metrology, analytical methods, and standardized test methods.

*Interagency Planning, Coordination, and Collaboration Supporting the 2006 Request*

**NIH (NCI), NIST, FDA:** Collaborate on the development of the NCI Nanotechnology Characterization Laboratory characterization cascade.

**NIST, all NNI agencies, and NNCO:** Coordinate and provide funding and staff support for the ANSI-NSP activity described above.

**NIST, NIH (NCI), FDA, and EPA:** Collaborate to address nanoparticle metrology.

**NIST, other NNI agencies:** A forthcoming NNI workshop report on "instrumentation and metrology for nanotechnology" will provide a framework for planning all NNI agencies' R&D related to this PCA.

**NIST, NASA:** Collaboratively develop measurement protocols for nanotube characterization and fabrication.

**2005 and 2006 Activities by Agency**

**DOD:** Develop breakthrough next-generation instrumentation for developing 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:** Initiate acquisition of a transmission electron aberration-corrected microscope (TEAM), a major instrument taking advantage of recent advancements in correction of electromagnetic lens defects to reach previously unobtainable performance levels. The design and development of TEAM is a multi-year project involving electron scattering research groups from five DOE laboratories in collaboration with industrial partners. New beam line instrumentation will be installed at neutron scattering centers to facilitate investigation of nanostructures; enhancement of beam line instrumentation will continue in 2006 to provide unprecedented capabilities for dynamic characterization of nanomaterials properties such as structure and composition.

**NIH:** Provide critical infrastructure and characterization services to nanomaterial providers to accelerate the transition of basic nanoscale particles and devices into clinical applications, thereby reducing suffering and death from cancer. The NCI's Nanotechnology Characterization Laboratory 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 the Societal Dimensions PCA.

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

- Innovative atomic force microscopes (AFMs): an atomic force acoustic microscope (AFAM) for nanomechanical property measurement, and an AFM-based chemical microscopy technique using functionalized nanoprobe 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 nanoparticles and nanopigments
- Methodologies and techniques for fabricating, characterizing, and modeling nanomaterials used for high fire-resistance materials and fire-fighter protection

**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 measurement of nanoscale domains of engineering relevance. Through the Office of Interdisciplinary Activities' Major Research Instrumentation program and the Division of Materials Research, several NSF-supported multidisciplinary user facilities also will provide support to nanotechnology research under this PCA. These user facilities include the Cornell High-Energy Synchrotron Source (CHESS), the Synchrotron Research Center (SRC) at the University of Wisconsin, the Center for High-Resolution Neutron Scattering (CHRNS), and the National High Magnetic Field Laboratory (NHMFL).

**USPTO:** USPTO's 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 the Fundamental Nanoscale Phenomena and Processes PCA.

## Nanomanufacturing

**NNI Agencies Requesting 2006 Funding for R&D Related to This PCA:** *DOC (NIST), DOD, NASA, NSF, USDA*

**Other Participating Agencies:** *DOC (BIS), DOC (TA), DOC (USPTO), DOE, DOT, EPA, HHS (NIH), HHS (NIOSH), IC, ITC*

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, manufacturing is 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.

### President's 2006 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 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 pre-competitive nanomanufacturing problems such as scale-up and reproducibility of nanomanufacturing processes
- Establishment of one or more centers focused on nanomanufacturing research, as called for in the Act, via collaborative efforts among existing Federal agencies, programs, and offices with interests in manufacturing
- NSET Subcommittee coordination with other Federal efforts to enhance the manufacturing infrastructure of the United States, providing jobs and other economic benefit
- Efforts to seek and utilize advice from the electronics, chemical and other industries to sharpen the NNI program

#### *Highlights of the 2006 Request*

- Establishment and coordination of a network for nanomanufacturing based on an NSF Center for Hierarchical Nanomanufacturing, a DOD Multidisciplinary Research Program of the University Research Initiative (MURI), and the NIST National Nanomanufacturing and Nanometrology Facility (N<sup>3</sup>F)—all expected to be fully operational in 2006
- Identification of appropriate opportunities to introduce nanomanufacturing into the DOD Manufacturing Technology (MANTECH) program
- Multiple programs to develop new metrology and characterization tools suitable for manufacturing environments
- NSET Subcommittee participation in the newly formed NSTC Interagency Working Group on Manufacturing Research and Development (IWGM)

#### *Interagency Planning, Coordination, and Collaboration Supporting the 2006 Request*

**DOD, NSF, NIST:** Coordination of program plans and program reviews for nanomanufacturing R&D efforts, including four NSF Nanoscale Science and Engineering Centers (NSECs) and the DOD MURIs, and for development of R&D partnerships.

**DOC (NIST, TA):** The Department of Commerce (NIST and TA) will play a leading role in the NSTC Interagency Working Group on Manufacturing Research and Development. The IWGM is chartered to identify and integrate requirements, conduct joint program planning, and develop joint strategies for manufacturing R&D programs conducted by the Federal Government, and has identified nanomanufacturing as one of three manufacturing R&D priority areas. TA will serve as a portal for industry input.

**USDA, NSF:** Developing new understanding of nano-biomaterials and nano-biodesives, which may be integrated into novel applications in nanomanufacturing.

#### **2005 and 2006 Activities by Agency**

**DOD:** Develop affordable approaches for manufacturing nanostructured bulk materials; 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; guide and monitor the introduction of nanotechnology into military hardware; identify appropriate opportunities to introduce nanomanufacturing into the DOD SBIR/STTR and MANTECH programs.

**DOE:** Develop collaboration platforms 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 (PBTs), hazardous air pollutants (HAPs) and volatile organic compounds (VOCs). 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 in development of technology for solvent-free production of nanometer-size high performance ceramic powders and similar materials.

**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.

**NIST:** The National Nanomanufacturing and Nanometrology Facility centered at the Advanced Measurement Laboratory (AML) opened and began initial operations in Gaithersburg, MD, in 2005. This facility enables fabrication of new nanoscale devices, instruments and standards; provides access to expensive nanofabrication tools and specialized expertise; and fosters collaboration in nanotechnology with external partners. Additionally, emphasis is being placed on developing new metrologies in support of nanomanufacturing including:

- Phase-sensitive scatterfield optical imaging for sub-10 nm dimensional metrology: NIST is embarking on a 5-year competence project to advance optical microscopy to unprecedented levels of performance. Initial simulations indicate that the resolution of this technique could ultimately surpass 10 nm, which would give manufacturers the ability to measure linewidth, feature overlay, and defects in nanoelectronic devices using high-throughput optical methods.
- Force dissemination for quantitative nanomechanical testing: NIST is working on critical pieces of metrology for use by primary, secondary, and industrial labs to support traceable quantitative measurement of forces below 10 millinewtons. This quantitative measurement of material and device response under mechanical force loading would enable materials testing, essential to wider acceptance of microscale and nanoscale engineered materials and systems.
- Novel fabrication platforms for testing functionality and operation of nanoimprint lithography, nanojet deposition, and other nanodevices.

- New test standards with atomic accuracy capability and integrity.
- Database of properties of atomic and molecular interactions with various materials to facilitate autonomous atom-by-atom assembly of nanostructures.
- High-accuracy positioners.
- New intrinsic calibration systems for basic physical properties.

**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. Ultra-miniaturized top-down processes and increasingly complex self-assembly (or other bottom-up) processes will be 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 will be 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. NSF expects to make an award for a Center for Hierarchical Nanomanufacturing in July 2005, which will become fully operational in 2006.

**USDA:** Explore novel opportunities to produce biologically based and bioinspired nanomaterials and nanodevices, and support research into the use of materials of agricultural and biological origin as feedstocks in nanomanufacturing.

**USPTO:** USPTO's activities designed to support the high level of commercial patenting activity in nanomanufacturing are described in the section on the Fundamental Nanoscale Phenomena and Processes PCA.

## Major Research Facilities and Instrumentation Acquisition

**NNI Agencies Requesting 2006 Funding Related to This PCA: DOC (NIST), DOD, DOE, HHS (NIH), NSF**

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

The NNI has invested substantial resources in establishing large multidisciplinary centers and user facilities as mechanisms to create environments that bring together and foster collaboration among groups of researchers from many disciplines. These centers and user facilities (see chart, next page) also provide access to advanced and often costly instrumentation. Provision of these resources is a critical component of the overall 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 distributed across the country to ensure easy access. Included in this PCA are facility planning; facility design and construction activities; acquisition of and bringing into operation instrumentation for nanoscience and nanotechnology research; and ongoing operation of instrumentation and facilities.

### President's 2006 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.
- Acquisition of best-in-the-world or state-of-the-art instrumentation for nanoscale imaging, measurement, characterization, and manipulation to support nanoscience and nanotechnology research at university and Federal Government laboratories.
- Leveraging Federal Government user facilities funded outside the NNI for nanotechnology R&D, such as X-ray and neutron sources and characterization tools.

DOE, NSF, and NIST fund facilities with these capabilities.

- Maintaining and improving nanoscale fabrication capabilities at Federal Government research laboratories. Ready access by Government researchers to world-class fabrication capabilities enables development of prototypical nanoscale test structures, measurement instruments, standard reference materials, electronic devices, NEMS/MEMS, and bio-devices critical to agency missions and to the Nation's nanotechnology needs.
- Creating an infrastructure that facilitates use of instrumentation and equipment from distant locations—true tele-operation of advanced instrumentation for imaging, characterization, and fabrication at the nanoscale.

#### *Highlights of the 2006 Request*

- Compilation of data on U.S. Government-supported user facilities and instrumentation. During 2006, all NSET Subcommittee member agencies will contribute to this effort and make that information accessible to the nanotechnology research community on the NNI website, [www.nano.gov](http://www.nano.gov).
- Establishment and expansion of facilities for conducting nanomanufacturing R&D—a major focus for this PCA in 2006. Examples described more fully in agency activities include the new NSF Center for Hierarchical Nanomanufacturing, NIST's N<sup>3</sup>F, transitioning of one of DOE's Nanoscale Science Research Centers (NSRCs) from construction and development to full operation, and completion of the NCI's Nanotechnology Characterization Laboratory.

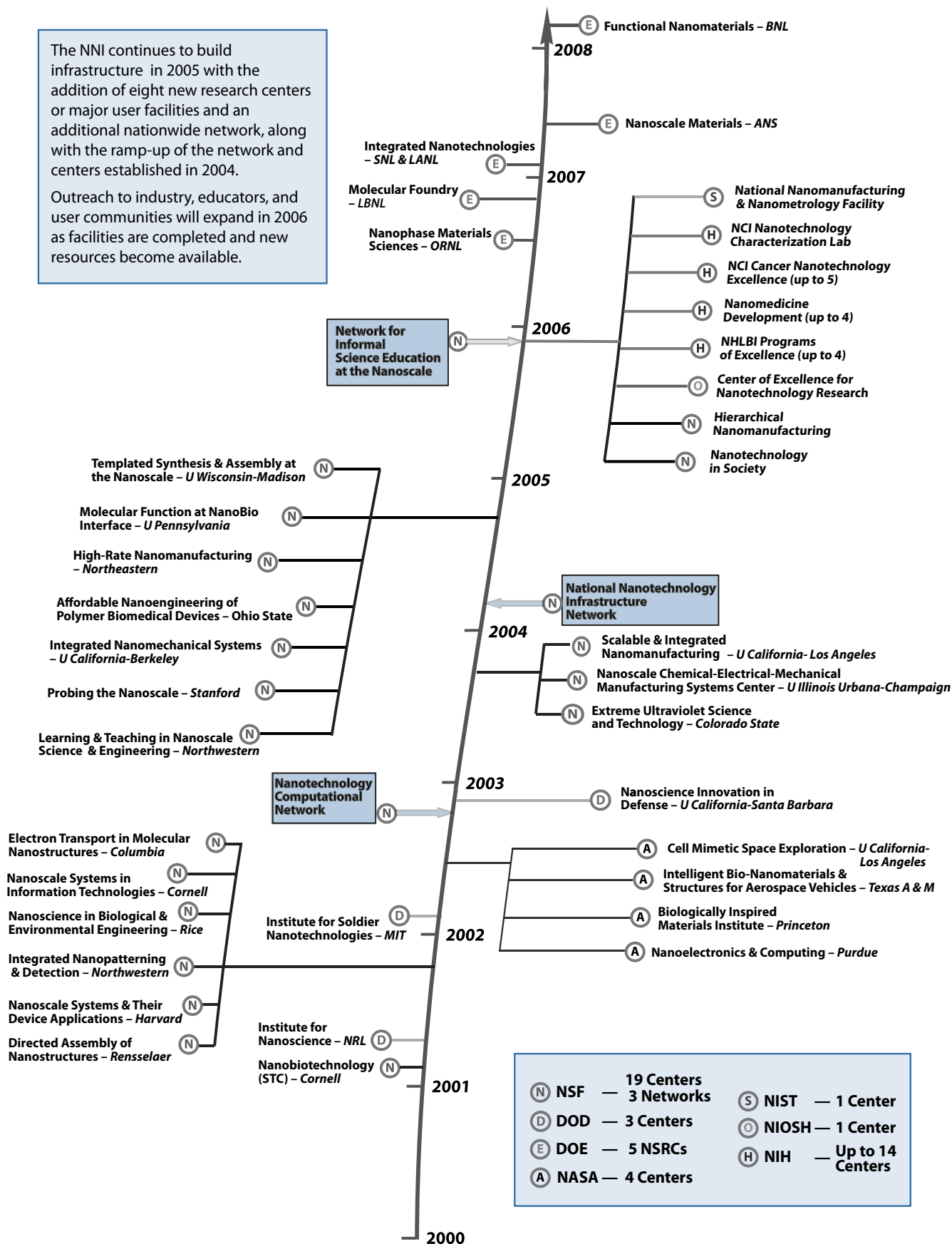
#### *Interagency Planning, Coordination, and Collaboration Supporting the 2006 Request*

**DOD, DOE, NASA, NSF, NIH:** The NIH Nanomedicine Roadmap anticipates that NIH

## NNI Centers and User Facilities

The NNI continues to build infrastructure in 2005 with the addition of eight new research centers or major user facilities and an additional nationwide network, along with the ramp-up of the network and centers established in 2004.

Outreach to industry, educators, and user communities will expand in 2006 as facilities are completed and new resources become available.



researchers will leverage the NNI infrastructure supported by other agencies to study the physical properties of intracellular structures. Utilizing NNI user facilities, centers of excellence, and other infrastructure resources, NNI funded researchers will gather information about how biology's molecular machines are built as the first step towards developing molecular-scale medical interventions.

**DOE, NSF, EPA, USDA:** DOE NSRC staff members are having ongoing discussions of NSRC capabilities with the staff and/or grantees of other agencies (including NSF, EPA, and USDA) and expect to continue and expand such dialogues. Each NSRC also will hold annual user meetings as they move into full operation. Meetings involving all NNI-supported facilities and centers are under consideration.

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

**NSF, DOD, NASA, DOE:** Plans and activities at NSF's National Nanotechnology Infrastructure Network (NNIN) and Network for Computational Nanotechnology (NCN) are coordinated with centers funded by DOD, NASA, and DOE.

### **2005 and 2006 Activities by Agency**

**DOD:** Provide advanced nanoscience instrumentation to universities via the Defense University Research Instrumentation Program (DURIP); further enhance nanoscience facilities and instrumentation available for use in the DOD in-house laboratories.

**DOE:** A major highlight in 2006 will be the transition from construction and development to full operation of the first of five DOE NSRCs, the Center for Nanophase Materials Science at the Oak Ridge National Laboratory. In addition, three other NSRCs will formally begin user operations as their buildings are completed. 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. Collectively, they constitute the major scientific infrastructure investment under the NNI.

**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.

**NIST:** As previously described in the nanomanufacturing PCA section of this report, NIST's N<sup>3</sup>F consists of the extensive Nanofabrication Laboratory Module of the AML augmented by select instrumentation within AML and NIST's laboratories that support nanomanufacturing and nanofabrication. Key N<sup>3</sup>F facilities will be opened beginning in 2006 and 2007 to qualified external collaborators from industry, academia, and government.

The NIST Center for Neutron Research will expand to enable greater user access to nanocharacterization tools. Upgrading of NIST's Boulder nanofabrication capabilities will continue with the acquisition and installation of a new field emission scanning electron microscope, which will be able to image nanoscale devices and to fabricate 20 nm or smaller devices via electron beam lithography.

**NSF:** Continued funding will be provided for 18 centers of excellence—the Nanoscale Science Engineering Centers (NSECs)—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, one new NSEC on nanomanufacturing will be established, 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, will

have roles in disseminating information and supporting nanotechnology activities at the national level.

**TA:** Continue to serve as an advocate for NIST's AML, which will operate a nanomanufacturing and nanometrology facility (N<sup>3</sup>F, see above) that will become

a user facility for industry, academic, and government researchers in 2006 and 2007. Researchers will be able to fabricate prototypical nanoscale test structures, standard reference materials, and electronic devices.

## Societal Dimensions

**NNI Agencies Requesting 2006 Funding for R&D Related to This PCA:** *DOC (NIST), DOD, DOE, DOJ, EPA, HHS (NIH), HHS (NIOSH), NSF, USDA*

**Other Participating Agencies:** *CPSC, DOC (TA), DOS, HHS (FDA), IC, ITC*

The Societal Dimensions PCA focuses on the practical implications and cultural context of nanotechnology research and development, on both a domestic and global scale. This PCA encompasses three subtopics: (a) research directed at environmental, health, and safety (EHS) impacts of nanotechnology development and risk assessment of such impacts; (b) education-related activities such as development of materials for schools, undergraduate programs, technical training, and public outreach; and (c) research directed at identifying and quantifying the broad implications of nanotechnology for society, including social, economic, workforce, educational, ethical, and legal implications. By developing these elements concurrently with its scientific research programs, the NNI facilitates public understanding of nanotechnology, is better able to proactively address public concerns and identify possible pitfalls, and can more effectively direct resources to optimize the benefits of nanotechnology. Cultivating public trust through open communications, education, policy foresight, and cooperation with the international community is important. Public awareness, acceptance of, and knowledge about nanotechnology are essential for fully realizing its potential economic and societal benefits. Equally important is the need to identify and address legitimate environmental, health, and safety issues.

### President's 2006 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 positive or negative environmental impacts of the application of nanotechnology
- Efforts to assure 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 various audiences at all age levels, "K to gray"
- Research on long-term societal, ethical, legal, and economic implications of nanotechnology; 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 appropriate information and education

*Highlights of the 2006 Request*

- ❑ Expanded joint extramural research program addressing potential environmental implications of nanotechnology, including EPA, NSF, NIOSH, and USDA. The partnership will also include the European Commission.
- ❑ Development of standards for environmental and toxicological studies of nanoparticles, and a metrology infrastructure supporting these standards.
- ❑ Major university-based toxicity study programs funded at the University of Houston and at the University of Rochester.
- ❑ Identification and addressing of nanotechnology R&D needed to support regulatory decision-making through coordination provided by the NSET Subcommittee's Nanotechnology Environment and Health Implications (NEHI) Working Group.
- ❑ Coordination of national and international efforts aimed at responsible development 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. The center will train teachers and education leaders in grades 7-16, with the aim of reaching one million students in the next five years.
- ❑ Funding of an NSF Center on Nanotechnology Informal Science Education, which will support a national network of science museums providing informal educational activities for schoolchildren as well as adults.
- ❑ Establishment of the NSF Center for Nanotechnology in Society, through which a network of social scientists, economists, and nanotechnology researchers will address key issues of societal implications of nanoscience and nanotechnology.
- ❑ Use of the National Toxicology Program (NTP), a multi-agency program administered by the National Institutes of Health, to study the potential toxicity of nanomaterials, and to pioneer inhalation exposure studies for engineered nanomaterials such as single-walled carbon nanotubes and quantum dots.

*Interagency Planning, Coordination, and Collaboration Supporting the 2006 Request*

**All agencies:** Coordinate approaches to regulation of nanotechnology-enabled devices and products through participation in the NEHI Working Group.

**EPA, NSF, NIOSH:** In 2005, EPA is partnering with NIOSH and NSF on a joint interagency competitive grant solicitation addressing environmental and health implications of engineered nanomaterials. Plans are to expand the partnership in 2006.

**FDA, NIH (National Institute of Environmental Health Sciences, NIEHS), NIOSH, and CPSC:**

Partnering to manage and operate the Toxicological Evaluation of Nanoscale Materials program within the NTP.

**NIOSH, FDA:** NIOSH and FDA co-chair the NEHI Working Group of the NSET Subcommittee. Fifteen agencies participate in the working group, including CPSC, DOE, DOD, EPA, FDA, ITC, NASA, NIEHS, NIOSH, NIST, NSF, OMB, OSTP, OSHA, and USDA.

**NIOSH, DOE:** Collaborating 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 nano-safety issues at the DOE NSRCs, including ideas for safe facility design and operation.

**NIOSH, all NNI agencies:** Sponsorship of the Second International Symposium on Nanotechnology and Occupational Health (Minneapolis MN, October 2005). NSET Subcommittee member agencies will participate in the organizing committee and all NSET Subcommittee member agencies are invited.

**NIST, NIH:** Collaborating to characterize fundamental properties of zinc oxide and titanium oxide nanoparticles commonly used in sunscreen lotions.

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

**NIH (NCI), NSF:** Leveraging agency strengths to build support for broad-based nanotechnology training and cross-disciplinary outreach efforts, particularly at the undergraduate level.

**NNCO, FDA, NIST, NIOSH, OSTP:** The Director of NNCO serves as Co-Chair and agency representatives have membership on the ANSI-NSP Steering Committee and panel.

**NSF, all other NNI agencies:** Conducting meetings for NSF grantees, including a forum on education and one on EHS aspects of nanotechnology in the NSECs. All NSET Subcommittee member agencies are invited to

participate. NSF will collaborate with the Department of Education in the area of nanotechnology K-12 education.

### **2005 and 2006 Activities by Agency**

**DOD:** Carry out research aimed at protecting the health and safety of warfighters who utilize future nanotechnology-based applications. Support research to enable physicochemical characterization and toxicology for water, air, and space environments. Provide support for a multidisciplinary education system capable of sustaining the skilled workforce needed to meet future defense needs. Assess, avoid, and abate adverse

## **International Cooperation on Responsible Development of Nanotechnology**

Responsible development of nanotechnology concerns a multitude of factors that contribute to (1) the commercialization of widely beneficial applications, (2) simultaneous planning for societal changes that could result from such innovation, and (3) the avoidance of potential negative impacts from new products. Because technological innovation is a global phenomenon, responsible development will be achieved most effectively through international cooperation.

An international dialogue on responsible development of nanotechnology was launched in June 2004, when a group of experts met in Alexandria, VA. Convened by the National Science Foundation, the meeting involved participants from 25 countries and the European Union who addressed opportunities for international cooperation and coordination.

Addressing the participants, Dr. John Marburger, director of the U.S. Office of Science and Technology Policy, said that “if we are to realize the full potential of nanotechnology for our nations, and for the developing nations that can share its benefits, then we are going to have to agree particularly on standards and nomenclature, on issues of intellectual property protections, and the need for responsible oversight and regulation of hazards that we may discover in these technologies.”

Central to discussion at the two-day meeting was how governments could best balance their efforts to promote innovation with efforts to reduce, minimize or, when possible, eliminate the risks and unintended consequences of nanotechnology. Emphasis also was given to facilitating information exchange on societal, health, and environmental research across the spectrum of applications expected to emerge from breakthroughs in nanoscience.

At the conclusion of the meeting, a preparatory group was formed to draft a plan of action for continued international dialogue and cooperation.

Proceedings of the workshop, entitled International Dialogue on Responsible Research and Development of Nanotechnology, are available from the Meridian Institute website ([http://www.nanoandthepoor.org/Final\\_Report\\_Responsible\\_Nanotech\\_RD\\_040812.pdf](http://www.nanoandthepoor.org/Final_Report_Responsible_Nanotech_RD_040812.pdf)).



environmental or health impact from defense utilization of nanotechnology.

DOD sponsors the National Defense Science and Engineering Graduate Fellowship Program (<http://www.asee.org/resources/fellowships/ndseg/>). Further, DOD collaborates with NSF in the NSF-Navy Civilian Service Fellowship/Scholarship program. This program seeks students at the bachelors, masters, or doctoral level in science, technology, engineering, and mathematics who wish to commit a portion of their careers to serve at a Navy R&D center (<http://www.nsf.gov/pubs/2004/nsf0427/nsf0427.pdf>).

**DOE:** Support research on fate and transport of nanoscale particles in the environment; develop informational materials on nanoscience research activities and user facilities; and interact with public audiences (students, local communities, media, and others) as an integral part of Nanoscale Science Research Center activities.

**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 exposures of humans and other species to nanomaterials, to obtain information used in risk assessment, a central aspect of EPA's mission. Potentially harmful effects of nanotechnology might arise as a result of the nature of the nanoparticles themselves, the characteristics of the products made from them, or aspects of the manufacturing processes involved. It is unknown whether nanomaterials bioaccumulate and thereby pose human health and environmental risks, and little is known about the fate, transport, and transformation of

nanoscale materials after they enter the environment. EPA, NSF, and NIOSH will fund appropriate research proposals from a competitive solicitation that addresses these issues. This will build on and complement 12 projects in these areas funded in 2004 under a similar program from EPA.

**NIH:** Under the NTP's broad-based research program to address potential human health hazards from unintentional exposure associated with the manufacture and use of nanoscale materials, investigate toxicology of nanoscale materials of current or projected commercial importance. Three of the NSET agencies form the core of the NTP: the National Institute of Environmental Health Sciences of the National Institutes of Health (NIEHS/NIH), NIOSH/Centers for Disease Control and Prevention, and the National Center for Toxicological Research (NCTR) of the FDA.

The program is studying skin uptake, inhalation, and oral routes of exposure and includes the following:

- 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 this NTP activity is contributed by NIEHS. The FDA National Center for Toxicological Research contributes the use of state-of-the-art capabilities of its NTP Phototoxicology Center. This activity is expanding in 2005 and 2006.

Second, the NCI's Nanotechnology Characterization Laboratory (NCL, <http://ncl.cancer.gov>—described above under the PCA on Instrumentation Research, Metrology, and Standards) will provide critical infrastructure for studies supporting decision-making about the implications of nanotechnology-based products. It will develop a characterization cascade

for use in preclinical evaluations of nanomaterials intended for cancer therapeutics. As part of its assay cascade, the NCL will characterize nanoparticles' 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 nanoparticles, 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. This work also will lay a scientific foundation that will enable the FDA to make sound decisions concerning the testing and approval of nanoscale cancer diagnostics, imaging agents, and therapeutics.

HHS 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 for diagnostic devices, routinely examine the interaction of cells or biological fluids with the devices. Much can be learned from these studies about biocompatibility, which in turn related also to potential toxicity.

The NCI Alliance for Nanotechnology in Cancer is supporting the education, training, and career development of post-doctoral as well as mid-career investigators for multi-disciplinary nano-oncology research (<http://grants.nih.gov/grants/guide/rfa-files/RFA-CA-05-025.html>). NCI expects to award approximately 36 new grants in this area. NCI also is making some programmatic investment of note in broad outreach and communication efforts via its publications and website ([nano.cancer.gov](http://nano.cancer.gov)) regarding nanotechnology research and development as it relates to cancer and other biomedical applications.

The NHLBI nanotechnology centers program (reported under the PCA on Nanoscale Devices and Systems) also includes a research training component.

**NIOSH:** Support research on nanotechnology issues associated with worker safety and health through intramural and extramural programs, including assessments of the use of nanotechnologies to increase worker safety and protect health, and research into toxicity and other potential harmful effects of exposure to nanomaterials. In 2005 and 2006: (a) continue to develop and expand partnerships and collaborations with stakeholders including industry, other agencies, and academia; (b) finalize the establishment of the NIOSH Nanotechnology Research Center to provide a framework for coordination and direction of intramural and extramural research programs addressing nanotechnology implications for worker safety and health; (c) evaluate occupational exposures to engineered nanomaterials, addressing effective exposure control in the workplace; and (d) with OSHA, develop guidelines for working with engineered nanomaterials. Coordinating with other NSET Subcommittee agencies in preparation of guidance for the research community, industry, and the public on "best practices" for safe handling of nanomaterials.

**NIST:** Develop measurement methods for *in vitro* diagnostics, standards for advanced healthcare and therapeutics, and metrology methodology for nanoparticles.

**NSF:** Support 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
- Development of educational materials and curricula for schools, new teaching tools, technical training programs, and public outreach programs
- Support for participation in nanoscience and nanoengineering research by undergraduates 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

In addition to the more specific activities above, two new NSF-wide program solicitations issued in 2005—one focused on research (Nanoscale Science and Engineering) and another on education (Nanoscale Science and Engineering Education)—continue to expand the agency’s broad-based support for the creation of knowledge at the nanoscale across all disciplines, in targeted solicitations as well as core programs.

Each of the 16 NSECs and the 13 NNIN nodes includes components on EHS; ethical, legal and other societal issues; education; outreach; and interaction with the public in their programs. Collectively, they support the education and training of about 10,000 graduate and undergraduate students, postdoctoral fellows, and teachers each year. Additional Research Experience for Undergraduates (REU) Program sites will be established at NSECs on a competitive basis. The new NSF-sponsored NSEC on Nanotechnology in Society will provide a framework for addressing the most important societal implications of nanotechnology, while

the Center for Informal Nanotechnology Education will open a broad net of activities to reach science museums around the country.

**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.

**USDA:** Develop new educational materials 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.



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### 3. NNI Investments for 2005 and 2006

The 2006 NNI budget request for nanotechnology R&D across the Federal Government is \$1.05 billion. The increase in spending for nanotechnology over the last five years (from an estimated \$464 million in 2001) reflects this Administration's continuing support for the NNI, 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.

A detailed summary of the NNI investments for 2005 and 2006 is provided in Tables 3, 4, and 5. Table 3 provides the 2004 actual budget, the 2005 estimated budget, and the 2006 funding request for those Federal agencies with R&D budgets dedicated to nanotechnology research and development. Table 4 provides 2006 planned investments by Program Component Area for each of these agencies. Finally, Table 5 shows 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.

Key points about the NNI investments:

- The 2006 Budget request is \$1.05 billion across eleven agencies for nanotechnology R&D.
- In 2005, NNI investments will total \$1.08 billion, a 9% increase over the 2004 actual investment.
- The increase from the 2004 actual to the 2005 estimated budget includes \$82 million in additional R&D funding for NSF, reflecting the growing importance of nanotechnology across the broad mission of NSF, and \$36 million in additional R&D funding at HHS (NIH), reflecting an increased emphasis on advancing nanotechnology-based biomedical R&D.
- Agencies with the largest budget requests and their areas of emphasis in 2005 and 2006 are:

- o NSF, which will support the formation of new centers of excellence in nanomanufacturing, understanding societal issues, and nanotechnology education, and which will increase support for multidisciplinary research.
- o HHS, which is funding the National Cancer Institute's Alliance for Nanotechnology in Cancer, the National Institute of Environmental Health Sciences/National Toxicology Program study of nanoscale materials, and a new activity at the National Institute for Occupational Safety and Health (NIOSH) to address implications and applications of nanotechnology for health and safety in the workplace. These HHS funding activities were initiated in 2005 and will reach full operation in 2006.
- o DOD, which is increasing its emphasis on applications development of materials, devices, and systems that address the use of nanotechnology toward the agency's mission.
- o DOE, which continues its funding for five Nanoscale Science Research Centers.
- o NIST, which recently opened the Advanced Measurement Laboratory and National Nanomanufacturing and Nanometrology Facility to provide research equipment and infrastructure with forefront capabilities that, when fully developed, will be broadly available to researchers from government, academia, and industry.

2005 and 2006 are transitional years for the NNI budget reports due to the new investment structure based on PCAs delineated in the NNI Strategic Plan and described in Section 1 of this report. Estimates by the agencies for their investments in each PCA are based on the descriptions of the PCAs provided in Section 1. 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 2.

	2004 Actual	2005 Estimate	2006 Request
NSF	256	338	344
DOD*	291	257	230
DOE	202	210	207
HHS (NIH)	106	142	144
DOC (NIST)	77	75	75
NASA	47	45	32
USDA	2	3	11
EPA	5	5	5
HHS (NIOSH)		3	3
DOJ	2	2	2
DHS	1	1	1
<b>TOTAL</b>	<b>989</b>	<b>1,081</b>	<b>1,054</b>

\* In DOD, the assessment of FY 2004 and FY 2005 funding for nanotechnology subsequent to Congressional changes is incomplete. In 2006, DOD will reassess which of its assigned R&D projects are appropriate to count as part of the nanotechnology crosscut, and any changes will be reported in subsequent nanotechnology publications.

	Fundamental Nanoscale Phenomena and Processes	Nanomaterials	Nanoscale Devices and Systems	Instrumentation Research, Metrology, and Standards for Nanotechnology	Nanomanufacturing	Major Research Facilities and Instrumentation Acquisition	Societal Dimensions	NNI Total**
NSF	95	75	54	12	24	24	60	344
DOD	35	83	99	3	2	6	2	230
DOE	48	33	5	11	0	109	1	207
HHS (NIH)	46	17	67	6	0	1	8	144
DOC (NIST)	5	1	2	39	19	8	1	75
NASA	4	17	10	0	1	0	0	32
USDA	1	2	6	0	1	0	1	11
EPA	< 0.5	0	< 0.5	0	0	0	4	5
HHS (NIOSH)	0	0	0	0	0	0	3	3
DOJ	0	0	0	0	0	0	2	2
DHS	0	0	1	0	0	0	0	1
<b>TOTAL</b>	<b>234</b>	<b>228</b>	<b>244</b>	<b>71</b>	<b>47</b>	<b>148</b>	<b>82</b>	<b>1,054</b>

\*\* Totals may not add due to rounding.

### Investments Within Societal Dimensions PCA

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 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.**

All other funding in the Societal Dimensions PCA supports research on ethical, legal, or societal issues and education-related activities. As a part of the NNI, workshops have been organized on the societal implications of nanotechnology and as discovery of potential implications of the technology has been made, the investment in R&D to understand implications has been growing.

Table 5 shows the estimated NNI investments in the two categories described above. Using the above definition of R&D for EHS implications, the funding indicated in Table 5 does not include R&D within other PCAs that is relevant to, but not primarily directed at, EHS implications. For example, studies of the basic mechanisms of interactions between nanoscale materials and biological systems, or work to develop an application of nanotechnology that produces information related to potential toxicity of nanoscale components or of their fate and transport in the environment, are not included. It should also be noted that R&D on EHS implications is taking place in industry and in university and government laboratories around the world. As described in several of the PCAs, the NSET Subcommittee is coordinating actively with these efforts—both nationally and internationally.

### Utilization of SBIR and STTR Programs to Advance Nanotechnology

The NNI supports numerous activities designed to accelerate the transition of newly developed nanotechnologies 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. In 2005 and 2006, several agencies are naming nanotechnology as a focus area in their SBIR solicitations, including DOD, EPA, NIH, NSF, and USDA. The 21<sup>st</sup> Century Nanotechnology Research and Development Act explicitly calls for information on the use of the SBIR/STTR program in support of the NNI. However, the amount that is granted each year is not planned in advance, but depends on the proposals received in response to a given solicitation. Therefore, data are only available after grants have been awarded. To date, information on the amount of SBIR/STTR funding that has gone specifically toward nanotechnology research has not been collected. Data for SBIR and STTR grants made in 2004 were not available from the Small Business Administration at the time of this report. The NSET Subcommittee will submit an addendum to this report once the data are available.

<b>Table 5</b>		
<b>Estimates of 2006 NNI Investments within Societal Dimensions PCA</b>		
<b>(dollars in millions)</b>		
	<b>Environmental, Health, and Safety R&amp;D</b>	<b>Education and Ethical, Legal, and other Societal Issues</b>
NSF	24.0	35.5
DOD	1.0	1.0
DOE	0.5	0.6
HHS (NIH)	3.0	5.0
DOC (NIST)	0.9	0
NASA	0	0
USDA	0.5	0.5
EPA	4.0	0
HHS (NIOSH)	3.1	0
DOJ	1.5	0
DHS	0	0
<b>TOTAL*</b>	<b>38.5</b>	<b>42.6</b>

\* Totals do not add to the Societal Dimensions PCA total listed in Table 4, due to rounding.



## Agency Nanotechnology Programs in 2005 and 2006

This section provides narrative descriptions of single agency as well as multi-agency nanotechnology activities with an emphasis on changes from 2005 to 2006. The descriptions do not describe the full range of ongoing activities of the agencies in support of the NNI.

### Interagency Thrusts

As indicated previously, the new NNI Strategic Plan that takes effect in 2006 underlies the most significant changes in NNI interagency budget priorities and coordination activities supported by the 2006 budget request. The NNI goals and the newly established Program Component Areas (PCAs), which 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 2006 reflecting the goals and PCAs set out in the NNI Strategic Plan include nanomanufacturing, continued infrastructure development, promotion of technology transfer and commercialization, and responsible development of nanotechnology, including environmental, health, and safety research. Specific interagency activity highlights and areas of emphasis for 2006 include the following:

#### *Environmental, Health, and Safety Research*

EPA, NSF, NIOSH, and USDA plan an expanded joint extramural research program addressing potential EHS implications of nanotechnology, including development of standards for environmental and toxicological studies of nanoparticles, and a metrology infrastructure supporting these standards. 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 provides a forum for coordinating this interagency thrust. NSET is seeking input from industry to provide additional perspectives.

#### *Nanomanufacturing*

NSF's Center for Hierarchical Nanomanufacturing will become fully operational in 2006, as will the complementary DOD MURI, and the NIST N<sup>3</sup>F. 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 beyond its existing successful interactions with the semiconductor/electronics and chemical industries, seeking input from industry on research needs and opportunities for technology transfer from NNI-funded research activities. NSF's "Silicon Nanoelectronics and Beyond" activity may serve as a model for future collaborations with industries such as biotechnology, 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 this section of the report. DOD will place a new emphasis in 2006 on moving research innovations into applications in support of the DOD mission. NSET's informal working group on industry liaison will help to coordinate this interagency thrust.

#### *Standards Development*

The NSET Subcommittee member agencies will continue to provide in-kind contributions (i.e., staff time) and funding for the American National Standards Institute's Nanotechnology Standards Panel (ANSI-NSP), which is developing nomenclature and other standards in support of nanotechnology applications and commercialization. Particular effort will be devoted by NSET member agencies in 2006 to expediting this activity, which was initiated in 2004. Participation in national standardization activities and in activities getting underway within the International Standards Organization will be complemented and supported by standards and metrology research funded by NIST and other NNI agencies.

### *Infrastructure Development*

As described in detail in the previous section of this report, three new NSF nanotechnology research centers will be awarded in 2005 and will reach full 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 26. The NNI-funded infrastructure is further complemented by an array of large-scale research facilities and centers not specifically dedicated to nanotechnology research, but providing the specialized tools and light sources 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, which 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*

Although total DOD research funding is decreasing in 2006, Army, Navy and Air Force investment in applied

research (6.2) and prototyping projects (6.3) related to nanotechnology will grow in an effort to accelerate the transition of nanoscience research into mature nanotechnologies for use in military systems.

New DARPA nanotechnology programs are expected in 2006, leading to increases in planned spending as the fiscal year approaches; specific topics have yet to be identified, but the agency continues to emphasize the development of nanotechnology in applications important to national defense, such as quantum computation and nanoelectronic devices.

New nanotechnology R&D activities are being considered within the Defense Threat Reduction Agency (DTRA) and the U.S. Army Medical Research and Materiel Command.

#### *DOE*

The DOE Office of Basic Energy Sciences will increase support for basic research on nanoscale phenomena and processes and on nanomaterials, in support of developing a hydrogen economy. Funding levels for other fundamental nanoscale scientific research, at DOE National Laboratories and through grants to universities, remain similar in 2006 to those in 2005.

DOE's nanoscience flagship, the five 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. In 2006, NSRC investment emphasis will transition from the construction and development phase to operations. The first NSRC, the Center for Nanophase Materials Science at the Oak Ridge National Laboratory, will commence full operations, and three other NSRCs will formally begin initial user operations as their dedicated buildings are completed and instruments are installed.

#### *EPA*

EPA will continue to focus the majority of its research in 2006, as in 2005, on health and environmental implications of nanomaterials. EPA also will investigate nanoscale technology as solutions to environmental problems.

### *NASA*

A key thrust for NASA in 2006 will be the application of nanotechnology to space exploration, in keeping with the President's new Vision for Space Exploration announced in 2004. At a workshop cosponsored 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 multi-functional materials; (2) high density, low power electronics; (3) ultra-small 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 will lead to improved health of the population and to reduced suffering from disease and disability. There is no significant change in priorities from 2005 to 2006. However, several recently launched programs will expand in 2006: university/research institution-based basic research (e.g., the Nanoscience and Nanotechnology in Biology and Medicine Program) and an SBIR program (Bioengineering Nanotechnology Initiative).

The following are new NIH programs in 2005 and 2006:

- Nanomedicine Roadmap, NIH-wide
- Programs of Excellence in Nanotechnology, National Heart Lung and Blood Institute
- Alliance for Nanotechnology in Cancer, National Cancer Institute

### *NIOSH*

In 2006, NIOSH will finalize the establishment of a Center of Excellence for Nanotechnology Research, coordinating nanotechnology-related activities across the institute and addressing critical occupational health issues. 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.

### *NIST*

New nanomanufacturing and nanofabrication programs were inaugurated in 2005 to enhance support for research into nanoimprint lithography, particle metrology, and other manufacturing metrology techniques. These programs also support development and delivery of measurement and infrastructural technologies to provide traceable metrology, process-control, and quality assurance for nanoscale manufacturing.

Funding also will increase for research on measurements of nanomechanical properties, nanotube and nanoparticle metrology, and to produce nanoelectronic and nanophotonic devices.

The National Nanomanufacturing and Nanometrology Facility (N<sup>3</sup>F) opened in Gaithersburg, MD in 2005, and will be expanded in 2006. The N<sup>3</sup>F is being developed at NIST as a user facility to support the development of new metrology and standards for U.S. nanotechnology efforts. The N<sup>3</sup>F provides access to NIST's unique nanometrology and nanofabrication resources, including the facilities of the Advanced Measurement Laboratory, and NIST's world-class nanometrology experts.

### *NSF*

Awards for three new NSF Nanoscale Science and Engineering Centers (NSECs) will be announced in 2005, each the hub of a new layer in U.S. nanotechnology infrastructure: a Center for Hierarchical Nanomanufacturing, a Center for Nanotechnology in Society, and a Center for Nanotechnology Informal Science Education. They will become fully operational in 2006, joining NSF's existing National Nanotechnology

Infrastructure Network, Network for Computational Nanotechnology, sixteen Nanoscale Science and Engineering Centers, and Nanotechnology Center for Learning and Teaching, as national-level platforms for nanotechnology that include merit-review-based open access and that serve as clearinghouses for information. Research Experience for Undergraduate programs will be expanded at the NSECs.

An increased investment will support research and education on:

- Active nanostructures, systems of nanosystems and molecular nanosystems, with emphasis on architecture and fabrication of nanoscale devices and systems
- Understanding and controlling self-assembly of materials and systems
- Multi-disciplinary aspects of nanoscale science, engineering and technology, in particular at the nano-biology interface and the nano-information interface
- Understanding long-term societal implications of nanotechnology, and providing for public interaction
- Programs and teaching materials supporting early education related to nanotechnology

NSF will expand academic researcher partnerships with industry, medical facilities, and states through the Grand Opportunities for Academic Liaison with Industry and the Partnerships for Innovation programs.

NSF will maintain the dedicated nanotechnology theme within its SBIR/STTR programs, first established in 2000, at a level of approximately \$13 million for 2005 and 2006.

### *USDA*

The USDA nanotechnology program will expand substantially in 2006 while maintaining its programmatic directions. The program portfolio in the Cooperative State Research, Education, and Extension Service (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, and will expand.

### *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 2005 and 2006, as will specific nanotechnology-related training of patent examiners.

USPTO also is engaged in efforts to identify and classify nanotechnology-related patents. Utilization of the cross-reference digest Class 977/Dig.1 (entitled "Nanotechnology"), which was established in October 2004, provides the ability to search nanotechnology-related prior art, will improve patent quality, and allows the USPTO to better quantify nanotechnology patent activity.



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# Appendices

## Appendix A. Glossary

Act	Public Law 108-153, the 21 <sup>st</sup> Century Nanotechnology Research and Development Act
Agencies	Departments, agencies, and commissions within the Executive Branch of U.S. Federal Government
ANSI	American National Standards Institute
ARO	Army Research Office (DOD)
BIS	Bureau of Industry and Security (DOC)
CCNEs	Centers for Cancer Nanotechnology Excellence (NIH/NCI)
CPSC	Consumer Product Safety Commission
CT	Committee on Technology of the NSTC
DTRA	Defense Threat Reduction Agency
DHS	Department of Homeland Security
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
DURIP	Defense University Research Instrumentation Program (DOD)
EPA	Environmental Protection Agency
FDA	Food and Drug Administration (HHS)
HHS	Department of Health and Human Services
ITC	International Trade Commission
IC	Intelligence Community (represented on NSET by the Intelligence Technology Innovation Center)
MANTECH	Manufacturing Technology (DOD program)
MEMS	Microelectromechanical systems
MURI	Multidisciplinary Research Program of the University Research Initiative (DOD program)
N <sup>3</sup> F	National Nanomanufacturing and Nanometrology Facility (DOC/NIST)
NASA	National Aeronautics and Space Administration
NCI	National Cancer Institute (HHS/NIH)
NCL	Nanotechnology Characterization Laboratory (HHS/NIH/NCI)
NCTR	National Center for Toxicological Research (HHS/FDA)
NEHI	Nanotechnology Environmental and Health Implications Working Group of the NSET Subcommittee
NEMS	Nanoelectromechanical systems
NHLBI	National Heart, Lung, and Blood Institute (HHS/NIH)

NIEHS	National Institute of Environmental Health Sciences (HHS/NIH)
NIH	National Institutes of Health (HHS)
NIOSH	National Institute for Occupational Safety and Health (Centers for Disease Control and Prevention/HHS)
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
NSRC	Nanoscale Science Research Centers (DOE program)
NSP	Nanotechnology Standards Panel (ANSI)
NSTC	National Science and Technology Council
NTP	National Toxicology Program (HHS)
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
USPTO	U.S. Patent and Trademark Office (DOC)
TA	Technology Administration (DOC)
USDA	U.S. Department of Agriculture

## Appendix B. Summary of NNI Responses to the 2002 National Research Council Review

The 2002 National Research Council review of the National Nanotechnology Initiative, *Small Wonders, Endless Frontiers*, included ten recommendations for strengthening the initiative. These recommendations, along with the provisions of the 21st Century Nanotechnology Research and Development Act, were critical inputs to the development process for the NNI Strategic Plan, which NSET released in December 2004. Following is a list of current or planned activities responding to each recommendation.

***R1: The Office of Science and Technology Policy (OSTP) should establish an independent standing nanoscience and nanotechnology advisory board (NNAB) to provide advice to NSET members on research investment policy, strategy, program goals, and management processes.***

In July 2004, President Bush amended Executive Order 13226 to designate the President's Council of Advisors on Science and Technology (PCAST) as the National Nanotechnology Advisory Panel (NNAP). The NNAP is responsible for periodically assessing the NNI and advising the President on its progress and related recommendations. The NNAP is preparing its first report.

***R2: NSET should develop a crisp, compelling, overarching strategic plan. The plan would articulate short- (1 to 5 years), medium- (6 to 10 years), and long-range (beyond 10 years) goals and objectives. It should emphasize the long-range goals that move results out of the laboratory and into the service of society.***

The NNI Strategic Plan, which was released in December 2004, articulates the overarching vision and goals for the initiative, along with strategies by which those goals are to be achieved.

As described more fully in Section 1, the Strategic Plan details current and planned activities or objectives aimed at accomplishing each goal, and defines the NNI areas of investment or Program Component Areas (PCAs).

In 2005 and 2006, the NSET Subcommittee will develop research targets for each of the seven PCAs.

Whereas the plan represents a high-level interagency strategy, individual agencies are developing specific goals based on their respective missions. A good example of such an approach is the Cancer Nanotechnology Plan developed by the National Cancer Institute ([http://nano.cancer.gov/alliance\\_cancer\\_nanotechnology\\_plan.asp](http://nano.cancer.gov/alliance_cancer_nanotechnology_plan.asp)). This plan identifies key areas of opportunity for nanotechnology to address the NCI's vision for eliminating suffering and death from cancer, as well as measurable milestones for progress in each area.

***R3: The NNI should support long-term funding in nanoscale science and technology so that they can achieve their potential and promise.***

Support for long-term funding is embedded in the strategies for achieving each of the goals set out in the NNI Strategic Plan and is embodied in the activities and programs within the participating agencies. A component of the NNI that particularly represents this long-term commitment is the investment in infrastructure, including multidisciplinary centers that have lifetimes of 5 to 10 years and the construction of major research facilities dedicated to nanoscale science and technology R&D. The chart on page 26 of this report shows over two dozen centers already established, as well as additional centers now being planned.

In addition to supporting infrastructure, activities such as the NTP program to investigate the toxicity of nanomaterials and the NCI Nanotechnology Cancer Plan are examples of long-term planning for and commitment to nanotechnology research.

***R4: NSET should increase multiagency investments in research at the intersection between nanoscale technology and biology.***

The NSET Subcommittee has addressed multiagency investments in research at the intersection of nanoscale technology and biology in several ways. First, the NSET Subcommittee convened a workshop, with participation by multiple agencies as well as academics from a broad range of disciplines. The workshop was aimed at bridging the gaps between the nanotechnology and biology communities by inviting leaders from both communities and by identifying cross-cutting scientific opportunities

that can be realized only through effective collaborations among these communities. Workshop participants presented concrete examples of opportunities and needs at the interface of nanotechnology and biology. As suggested by the workshop, NNI activities are encouraging the formation of multidisciplinary teams in which participants will benefit from and contribute to each other's ongoing investigations, and ultimately open new lines of completely novel inquiry.

Second, NIH investments in research at the intersection of nanoscale technology and biology have increased significantly, and as described in the PCA subsections on "Interagency Planning, Coordination, and Collaboration in Support of the 2006 Request," a number of multiagency investments in this field are underway.

Third, programs at the nano-bio interface under joint agency sponsorship, initiated since the National Research Council report, include (a) the EPA-NSF-NIOSH solicitation for proposals to investigate Environmental and Human Health Effects of Manufactured Nanomaterials (which is expected to result in 15 to 20 awards in 2005) and (b) *in vivo* rodent studies of toxicity and uptake of fullerenes and semiconductor quantum dots under the National Toxicology Program (involving the FDA, NIOSH, and the NIEHS).

Finally, the NSET Subcommittee has formed a working group on Nanotechnology Environmental and Health Implications (NEHI) that is playing a very active role in research and regulatory issues at the bio/nano interface, including coordinating regulatory and standards development efforts and developing models for biological impacts of engineered nanomaterials.

***R5: NSET should create programs for the invention and development of new instruments for nanoscience.***

Over 60 universities have received NNI funding in support of nanotechnology facilities and instrumentation. Four national networks are developing state-of-the-art tools and instruments, and making them available to the research community as user facilities:

1. The National Nanotechnology Infrastructure Network (supported by NSF)
2. The Nanoscale Science Research Centers (supported by DOE, collocated at national laboratory sites)

3. The National Nanomanufacturing and Nanometrology Facility and Advanced Measurement Laboratory (supported by NIST)
4. The Network for Computational Nanotechnology (supported by NSF)

Research into novel experimental and computational tools will continue to receive high priority as part of the Instrumentation Research, Metrology, and Standards Program Component Area.

***R6: Create a special fund for Presidential grants, under OSTP management, to support interagency research programs relevant to nanoscale science and technology. These grants should be used exclusively to fund meaningful interagency collaborations that cross mission boundaries, particularly among the National Institutes of Health, the Department of Energy, and the National Science Foundation.***

While current authorities do not allow direct OSTP funding of programs as the National Research Council recommended, the NSET Subcommittee, with OSTP encouragement, continues to explore means for stimulating further interagency collaborations. The NEHI working group and joint EPA-NSF-NIOSH solicitations mentioned above, and the coordinated DOD-NSF-NIST activities in nanomanufacturing, as well as NIH-NSF-USDA and NIH-DOE cosponsored workshops, are examples of such activities.

***R7: NSET should provide strong support for the development of an interdisciplinary culture for nanoscale science and technology within the NNI.***

The educational programs, grant solicitations, and facilities use policies of the NNI all strongly encourage an interdisciplinary approach to nanoscale science and engineering. In particular, solicitations for centers of excellence and research teams require multidisciplinary participation. Over 40,000 practitioners from numerous disciplines have received training in at least one aspect of nanotechnology through NNI-sponsored programs. Educational programs at the middle and high school level, both in classrooms and in informal settings, are beginning to introduce nanoscience concepts. These programs are laying the groundwork for an interdisciplinary culture among tomorrow's nanotechnology researchers.



Several NIH activities focus on interdisciplinary research approaches. The Nanomedicine Roadmap Initiative envisions a cross-disciplinary effort with biologists, clinicians, physical scientists, engineers, and mathematicians to create new paradigms for treating disease and healing injured tissue. The National Cancer Institute has invited researchers from all disciplines to participate in its cancer nanotechnology programs, and supports career development grants for individuals trained in the basic, biomedical, clinical, and information sciences and engineering who wish to apply their knowledge and skills to critical problems in cancer research and clinical oncology.

*R8: Industrial partnerships should be stimulated and nurtured, both domestically and internationally, to help accelerate the commercialization of NNI developments. NSET should create support mechanisms for coordinating and leveraging state initiatives to organize regional competitive clusters for the development of nanoscale science and technology.*

The NSET Subcommittee's vision of a "grand coalition" of academe, government, industry, and professional groups contributing to the NNI is taking shape. Over 22 alliances have been formed throughout the United States at regional, state, and local levels to promote industrial partnerships in commercial or educational opportunities. In September 2003 the NSET Subcommittee and the NNCO brought together interested parties from 22 states and the District of Columbia to discuss common goals and practices and interact with representatives of NNI agencies.

The NSET Subcommittee and the NNCO have begun major outreach efforts to science, engineering, and health professional societies. Industry liaison activities also are underway with the electronics sector and the chemical sector, and are being initiated with several other major U.S. industrial sectors including aerospace, automotive, biotechnology, forest products, and plastics. Specifically, NSET has consulted with the electronics and chemical sectors; jointly organized workshops have resulted and reports from those workshops are available through the NNI website. Industrial participation also is critical to the standards activities the NSET Subcommittee has initiated in the past year under the auspices of the new

ANSI Nanotechnology Standards Panel. These industrial partnerships will be crucial to NNI Goal 2, facilitating transfer of new technologies into products for economic growth, jobs, and other public benefit.

*R9: NSET should develop a new funding strategy to ensure that the societal implications of nanoscale science and technology become an integral and vital component of the NNI.*

While research and education into societal implications of nanotechnology have been integral to NSET Subcommittee member agency plans since the inception of the NNI, they have received heightened attention in the past two years. Four interagency workshops on environmental, social, and medical issues were held in 2003 alone, and the number of research projects funded in these areas has grown significantly since the National Research Council made this recommendation. In accordance with the provisions of the Act, NSF opened a competition for a Center for Nanotechnology in Society and expects to make an award for this center in 2005.

The NNI Strategic Plan defines a Societal Dimensions Program Component Area, with subcategories for research related to environmental, health, and safety impacts; education and public outreach; and other broad implications of the development of nanotechnology including social, economic, ethical, legal, and workforce issues. Activities in this PCA directly support Goal 4 of that plan, Responsible Development of Nanotechnology.

*R10: NSET should develop performance metrics to assess the effectiveness of the NNI in meeting its objectives and goals.*

A component of the NNI Strategic Plan is the establishment of focused R&D objectives within each of the PCAs. As indicated in this Supplement to the President's 2006 Budget, the NSET Subcommittee member agencies plan to define these objectives in terms of "research targets" during 2005 and 2006. The NSET Subcommittee obtained recommendations from the academic and industrial communities for these research targets during the NNI Research Directions II workshop convened in September 2004.

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