The National Nanotechnology Initiative

Strategic Plan

Developed by the Nanoscale Science, Engineering and Technology Subcommittee

Committee on Technology

National Science and Technology Council

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About this document

This document is a strategic plan for the National Nanotechnology Initiative (NNI) describing the vision, goals, and strategies by which those goals are to be achieved. It represents the culmination of a series of activities designed to elicit community input from academia, industry, and government aimed at identifying cross-cutting themes and priority research opportunities for the NNI over the next five to ten years. The plan includes a description of the NNI investment strategy and the major categories of investment, or *program component areas.*

About the cover

Front cover: Photograph by Maximilian Franz courtesy of Reactive NanoTechnologies (RNT). Shown is an RNT NanoFoil™ containing thousands of alternating nanoscale layers of nickel and aluminum. With foils formed in this manner, an electrical pulse applied to the foil will initiate a mixing reaction producing high temperatures. The photograph shows the reaction propagating across the foil at 5 meters per second. This nano-foil is being used as a unique, localized heat source that enables bonding of components made from a wide variety of materials while heating only the interface between the components. The majority of each component remains at or near room temperature.

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Strategic Plan

Developed by the
Nanoscale Science, Engineering, and Technology Subcommittee
Committee on Technology
National Science and Technology Council

December 2004

Report prepared by

NATIONAL SCIENCE AND TECHNOLOGY COUNCIL

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EXECUTIVE OFFICE OF THE PRESIDENT
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December 7, 2004

Dear Colleague:

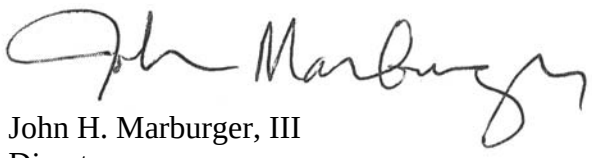
Over the past two decades, the ability to measure and manipulate matter at the scale of atoms and molecules has led to the discovery of novel materials and phenomena. These advances underlie the multidisciplinary areas of research and development (R&D) known today as "nanotechnology." Since its inception in Fiscal Year (FY) 2001, the National Nanotechnology Initiative (NNI) has sought to accelerate the responsible development and application of nanotechnology in order to create jobs and economic growth, to enhance national security, and to improve the quality of life for all citizens. Funding under the NNI has more than doubled since FY 2001 to a request in FY 2005 of nearly one billion dollars Government-wide. R&D supported by the NNI could lead to cleaner and less wasteful methods of manufacture, stronger and lighter building materials, smaller yet faster computers, and more powerful ways to detect and treat disease.

On December 3, 2003, the President signed into law the 21st Century Nanotechnology Research and Development Act (Public Law 108-153), thereby enacting many ongoing activities of the NNI. In addition to outlining a diverse R&D program, the Act also calls for the National Science and Technology Council (NSTC) to prepare a strategic plan for the Federal nanotechnology R&D program. This report, prepared by the Nanoscale Science, Engineering, and Technology Subcommittee of the NSTC, updates the original NNI strategic plan for the next 5 to 10 years.

The plan specifies goals that embody the importance not only of sustaining a world-class R&D program in nanotechnology, but also of advanced infrastructure and interdisciplinary education. The plan also addresses the societal dimensions related to the development of new technologies, including the potential implications for health and the environment, and the importance of dialogue with the public. Finally, the plan anticipates that Federal and private sector investment in R&D, education, and infrastructure will continue to lead to innovations that will enable new or improved products and services, and it identifies strategies to facilitate the commercialization and public utilization of those innovations.

In its first five years, the NNI, through the participating agencies, has advanced our knowledge of matter at the nanoscale and has made progress toward establishing the infrastructure needed to allow further scientific and technological breakthroughs. By implementing the plan described in this report over the next five years and beyond, the NNI will ensure that the United States remains a world leader in nanotechnology R&D and will facilitate the transition of results to strengthen the U.S. economy and to address national needs.

Sincerely,



John H. Marburger, III
Director

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EXECUTIVE SUMMARY

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

Toward 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. The initiative is a multi-agency, multidisciplinary program that supports research and development (R&D); develops infrastructure; and promotes education, knowledge diffusion, and commercialization in nanotechnology. Concurrent with development of new technology options, the NNI is addressing nanotechnology's various societal dimensions.

With the goal of achieving the above vision, the National Nanotechnology Initiative was launched in Fiscal Year (FY) 2001. Since that time, the annual Federal investment in nanotechnology R&D has more than doubled to almost $1 billion, the number of Federal agencies investing in nanotechnology R&D has grown from 6 to 11, and the total number of participating agencies has grown from 6 to 22. Participating agencies are those for which nanotechnology is relevant to the agency mission, including both those with and without nanotechnology R&D funding. Interagency coordination is managed through the Nanoscale Science, Engineering, and Technology (NSET) Subcommittee of the National Science and Technology Council (NSTC) Committee on Technology.

The strategy for the initiative that was laid out in 2001 has been, by all measures, a success. Nanotechnology R&D has led to substantial increases in scientific knowledge, publications, patents, and new jobs and businesses in this area. Much of this success is directly or indirectly based on the results of Federally funded R&D, and the NNI has become the model for similar programs around the world.

As the NNI has taken root and grown, the NSET Subcommittee has recognized the need to assess the initiative and to update its strategic plan by looking 5 to 10 years ahead. This report represents the culmination of a series of activities aimed at doing so. Specifically, over the past three years, the NNI sponsored 17 topical workshops focused on areas of nanotechnology applications, societal implications, and regional, state, and local initiatives. In September 2004, the overarching NNI Research Directions II Workshop brought together experts from academia, industry, and government to synthesize the output of the topical workshops and to identify cross-cutting themes and priority research opportunities. Taking into consideration the results of the various workshops, as well as the ongoing agency missions and needs for which nanotechnology will offer solutions, the NSET Subcommittee developed the NNI strategic plan that is described in this report.

This plan describes the goals of the NNI as well as the strategy by which those goals are to be achieved. The goals are as follows:

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

Ongoing activities as well as specific new activities aimed at achieving each goal are identified. As new materials and devices are created and novel applications developed, the NNI plans to target investments toward opportunities identified by the community via NNI-sponsored workshops, put greater emphasis on technology transfer and liaison with industry groups, and complete and operate user facilities.

At the same time as useful applications are being developed, the NNI recognizes the importance of, and plans to address, societal dimensions of nanotechnology. The areas of society that may be affected by nanotechnology include economic, education, workforce, ethical, and legal aspects. In addition, the NNI supports research aimed at understanding the benefits and risks to human health and the environment, and methods for nanotechnology risk assessment and management.

The plan also includes a description of the investment strategy, including the major subject categories of investment, or *program component areas* (PCAs). Whereas the NNI goals embody the vision of the initiative and provide structure for its strategy and plans, the PCAs relate to areas of investment that are critical to accomplishing those goals. These areas cut across the interests and needs of the participating agencies, and advancement may be expedited by grouping together work in a particular PCA that is taking place within multiple agencies. The program component areas are as follows:

- 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

Each PCA may include research that ranges from basic to applied, as well as development of applications based on nanotechnology.

The original implementation plan for the NNI identified nine "grand challenge" areas, corresponding to a variety of application areas in which nanotechnology is expected to have a significant impact. The plan described herein is organized somewhat differently, focusing on the overarching goals and the investment areas (PCAs), which underlie virtually all the former grand challenge areas. R&D that focuses on practical applications, such as energy, homeland security, healthcare, food and agriculture, and the environment, may cut across multiple PCAs. This plan also identifies agency participation in program component areas and in a number of application areas.

The NNI will provide a balanced and coordinated investment in the program component areas and in a broad spectrum of applications. This will ensure that the United States remains a global leader in the responsible development of nanotechnology and secures the resulting benefits to the economy, to national security, and to the quality of life of all citizens.

PREFACE

The ability to image, measure, model, and manipulate matter on the nanoscale is leading to new technologies that will impact virtually every sector of our economy and our daily lives. Nanoscale science and technology has the potential, for example, to increase the efficiency of lighting, enhance the performance of electronic devices, decrease waste and pollution during manufacturing, detect and treat disease at the earliest stages, and provide more cost-effective solar energy conversion. At the same time, care must be taken to develop new technologies for widespread use in a responsible manner.

What is Nanotechnology?

Nanotechnology is the understanding and control of matter at dimensions of roughly 1 to 100 nanometers, where unique phenomena enable novel applications. A nanometer is one-billionth of a meter; a sheet of paper is about 100,000 nanometers thick. Encompassing nanoscale science, engineering, and technology, nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale.

At this level, the physical, chemical, and biological properties of materials differ in fundamental and valuable ways from the properties of individual atoms and molecules or bulk matter. Nanotechnology R&D is directed toward understanding and creating improved materials, devices, and systems that exploit these new properties.

Achieving the benefits promised by nanotechnology will depend on advanced research in fields ranging from chemistry and engineering to biology and materials science; development and support of the necessary infrastructure, including user facilities and instrumentation; and education and training of a skilled workforce and an informed public.

The National Nanotechnology Initiative was established in Fiscal Year 2001 to coordinate the research and development of nanoscale science, engineering, and technology — or nanotechnology — across the Federal Government. In the first year of the NNI, six agencies were investing in nanotechnology R&D and the total Federal investment was $464 million. For FY 2005, the estimated funding totals nearly $1 billion for research across 11 agencies. The organization and strategy laid out in FY 2001 has effectively shaped and guided the initiative over its first four years.

Since FY 2001, research under the NNI has continued to expand understanding, knowledge, and the ability to control matter at the nanoscale. In 2002, the National Academies published a review of the NNI entitled, *Small Wonders, Endless Frontiers,* which was highly supportive of the NNI and its coordination by the NSET Subcommittee. Today, commercialization of the results of NNI research has begun. For example, researchers have developed methods for nanoscale imprinting, which can be used in the fabrication of electronic circuits and fluidic and optical devices. Progress also is being made in the ability to use biological organisms to assemble inorganic materials at the nanoscale. Such bottom-up methods of processing may someday be cheaper and less wasteful than current manufacturing methods. Other advances are described in the reports listed in Appendices B and C and on the NNI website at www.nano.gov.

Following the NNI's early success, virtually every other country with an organized science and technology program has increased investments in nanotechnology R&D. A number of estimates indicate that today the total outlay by governments worldwide is several times that of the United States, leading to greater opportunities for international collaboration. Global investment in nanotechnology will promote global benefits.

The NNI has led not only to investment by other countries, but also by U.S. regional, state, and local

authorities that are seeking to gain the economic benefits of nanotechnology research and its commercialization. As estimated at a recent NNI workshop, the identified combined investment by regional, state, and local entities is about 20% that of the Federal Government. Contributions to these state and local entities from additional sources such as private foundations are substantial and are not included in this estimate.

The private sector also is investing in nanotechnology R&D at a level comparable to or greater than the Federal R&D investment. Large companies in industries ranging from aerospace and automotive to chemicals and semiconductors are moving to incorporate nanotechnology into their products and processes. The venture capital community is making significant investments in nanotechnology-based start-ups, leading to a growing number of "pure play" nanotechnology businesses, many of which are developing entirely new products and approaches, for example, in medical imaging and therapeutics.

The importance of a coordinated Federal program for nanotechnology R&D was given even greater recognition with the enactment of the 21st Century Nanotechnology Research and Development Act (Public Law 108-153, hereafter referred to as "the Act"). 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 example, in addition to the agencies authorized through the Act, the responsibility of the Department of Defense to carry out nanotechnology R&D coordinated with the NNI was specifically addressed in the 2003 Defense Authorization Act (Public Law 107-314, Section 246). 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.

This report presents the strategic plan called for by the Act. In developing this plan, the NSET Subcommittee sought extensive advice and input from the academic, industrial, and government research communities and took into consideration the recommendations of the 2002 National Academies report. This plan represents the consensus of the participating agencies as to the goals and priorities of the NNI. The plan provides a framework (1) within which each agency will carry out its own mission-related nanotechnology programs, and (2) for coordination of interagency activities. In addition to specifying high-level goals, the plan identifies current and planned activities aimed at accomplishing those goals. The plan also identifies major subject areas — the program component areas called for by the Act — that group related projects, and in which investments are needed to ensure the success of the initiative. Finally, the plan details a number of application areas that cut across the program component areas and that align with the competencies and missions of participating agencies. The plan will facilitate achievement of the NNI vision by offering guidance for agencies, program managers, the research community, and industry in their nanotechnology R&D investments and activities.

NNI Participating Departments and Agencies, 2004 and 2005

Federal agencies and departments with R&D 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 of Occupational Safety and Health (NIOSH, Department of Health and Human Services)
National Institutes of Health (NIH, Department of Health and Human Services)
National Science Foundation (NSF)

Other participating agencies and departments

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)

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.

Toward this vision, the NNI will expedite the discovery, development, and deployment of nanotechnology in order to achieve responsible and sustainable economic benefit, 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.

GOALS AND PLANS

The four goals of the National Nanotechnology Initiative are as follows:

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

The remainder of this section presents expanded descriptions of each of the goals, including current efforts and new strategies for continued progress and success of the NNI. The included sidebars are examples of progress towards these goals or accomplishments to date.

GOAL 1: MAINTAIN A WORLD-CLASS RESEARCH AND DEVELOPMENT PROGRAM AIMED AT REALIZING THE FULL POTENTIAL OF NANOTECHNOLOGY

Federal R&D programs advance the boundaries of knowledge and develop technologies that address government and national needs. To accomplish the vision of the National Nanotechnology Initiative, a coordinated Federal investment is required at the frontiers and intersections of many disciplines, including biology, chemistry, engineering, materials, and physics. Activities aimed at making progress toward this goal include support for basic or knowledge-inspired research, application or use-inspired research, and technology development. Application areas of interest to both Government and industry include energy, environment, health, medicine, information technology, defense, transportation, and agriculture and food systems. NNI activities have produced significant progress in all of these and other areas, and are progressing from fundamental discovery to technological applications and commercialization.

Current Activities

The NNI funds a wide range of R&D within and across scientific and engineering disciplines in order to advance discovery and innovation in nanotechnology. Universities and other research institutions perform approximately two-thirds of the NNI R&D under grants, cooperative agreements, and contracts from NNI funding agencies. Roughly one quarter of NNI R&D is performed at government-owned laboratories. The remainder (about one-tenth) funds nanotechnology R&D at small businesses and other private sector entities.

R&D activities can be described as falling into the following three categories:

- ***Single investigators***

  Research directed by single investigators is a key component of the NNI R&D portfolio, and is considered critical to the continuing genesis and development of innovative concepts that will lead to breakthroughs in nanotechnology. Funding of individual investigators allows the NNI to support a broad range of ideas, as well as more "high risk" proposals that, if successful, may lead to major advances.

- ***Multi-investigator/team efforts***

  Research at the intersection of traditional disciplines is a requirement for rapid progress in both understanding nanoscale phenomena and developing nanotechnology applications. Consequently, funding of multidisciplinary teams that bring a range of expertise to bear on a particular research topic or technology problem is a hallmark of the NNI. Participating agencies employ a variety of mechanisms for this type of investment; for example, NSF currently dedicates at least 20% of its NNI investment to programs such as the Nanoscale Interdisciplinary Research Teams.

- ***Centers***

  For many of the same reasons, the NNI has invested substantial resources in establishing large multidisciplinary research centers (typically costing more than $2 million per year over 5 to 10 years). NSF has established 17 such research and education centers, DOD has established three research centers, and NASA has established four. Compared to the multi-investigator research teams, these centers have a broader scope and bring together a larger group of researchers with greater breadth of expertise. Some centers have leveraged the NNI investment to obtain additional laboratories, instrumentation, and equipment, providing even more extensive opportunities and support for nanotechnology R&D.

  Multi-investigator research teams and centers foster the development of scientists who have an understanding and appreciation of many converging disciplines. Such individuals are needed to fully exploit the opportunities and benefits offered by novel phenomena and processes at the nanoscale. In part due to investments in the teams and centers described above, both senior NNI-funded researchers and more junior scientists are developing an interdisciplinary culture that was uncommon in the R&D community of a decade or two ago.

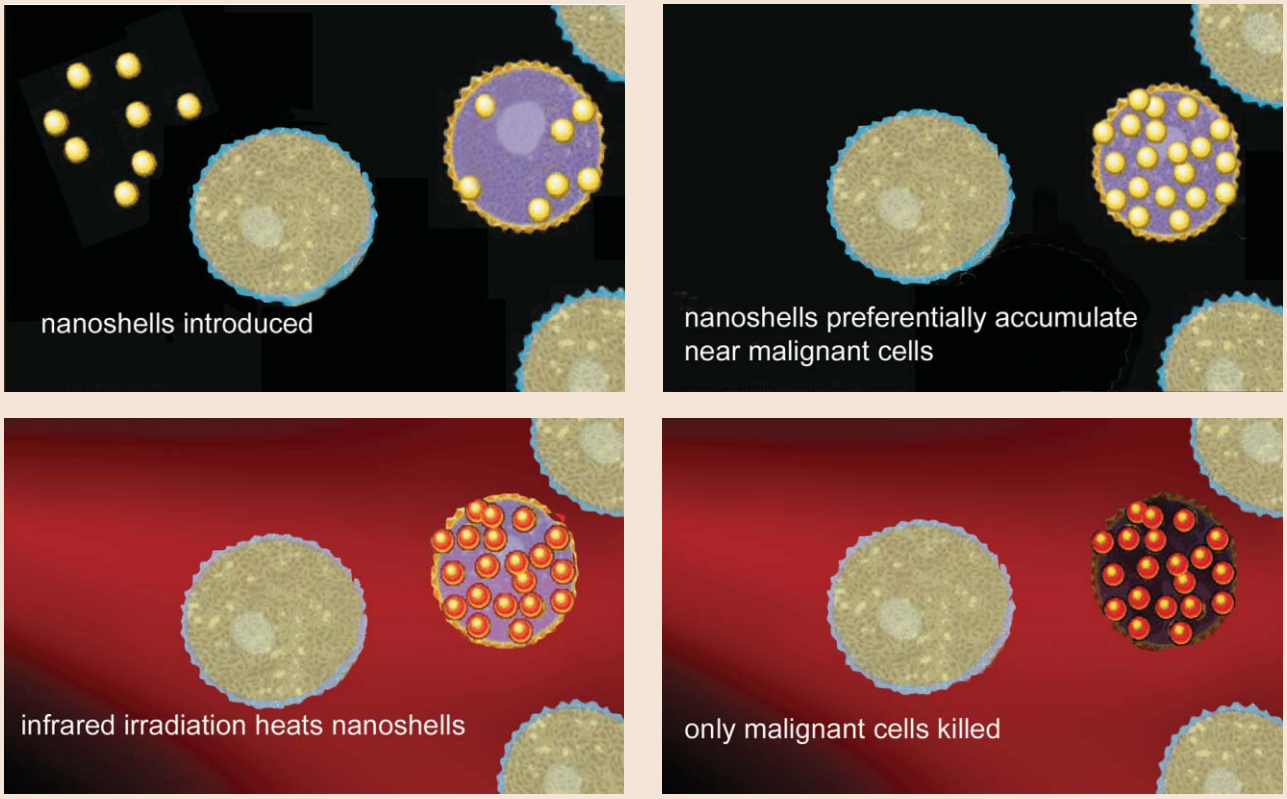
The NNI also stimulates interaction among stakeholders in the nanotechnology research community through various means, including setting of joint research directions, collaborative activities, multi-agency program funding, and grantees workshops. The NNI encourages R&D in partnership with industry and with the international research community.

Medical Researchers Target New Cancer Treatments

Despite great progress in the fight against cancer, one American dies from the disease every minute, and one out of every two men and one out of every three women in their lifetime will be told they have cancer. Nanotechnology could provide new treatments for many cancers with minimal side effects. One promising approach is the targeted destruction of malignant cells using localized heating. This procedure could be relatively simple to perform, minimally invasive, and useful in vital regions where surgical removal is out of the question. Previous approaches for using localized heating (including focused ultrasound energy, microwaves, and laser light) do not adequately discriminate between tumors and surrounding healthy tissue. Nanostructures that can seek out cancerous cells and then act as localized heat sources may prove to be key to practical thermal cancer therapies.

Researchers at Rice University, with funding from NSF and DOD, have carried out experiments in which they treat mice, in which cancer had been induced, with nanoparticle-enabled thermal therapy. Gold nanoshells of about 150 nanometers in diameter were injected into the bloodstream of these mice. This size nanoshell penetrates tumors but not healthy tissue. The nanoshells are also specifically designed to absorb infrared light that passes harmlessly through body tissue. The nanoshells heat up when they absorb the infrared light, thereby killing the nearby cancer cells.

Ninety days after mice with cancer were treated with this photothermal therapy, they appeared healthy and tumor-free, whereas untreated mice had to be euthanized after an average of 12 days due to extensive tumor growth. These researchers are now planning laboratory trials with larger mammals as the next step toward future clinical trials.



Courtesy Jennifer West, Rice Univ., National Cancer Institute, and NNCO staff

Plans

Because nanotechnology is still at an early phase of realization, the Research Directions II workshop participants emphasized the need for continued financial support, programmatic development, and technical focus of the NNI. Targeted investments and shared commitments among stakeholders are essential to accelerate social and economic benefits based on advancement and commercialization of nanotechnology.

The NNI plans to continue and build on current activities by adopting the following strategies:

- Sustain funding for exploratory research leading to the discovery and development of novel ideas. Such research includes the investigation of fundamental nanoscale phenomena, properties, processes, structures, and architectures, as well as development of experimental and simulation tools with high spatial and temporal resolution.
- Continue to invest in research in the enabling disciplines and in synergistic research at the intersection of the many disciplines encompassed by nanotechnology, through all three of the funding approaches described above (single-investigator, multi-investigator/team efforts, and centers). Utilize the existing center and network approach to encourage interdisciplinary projects and to incubate new concepts for industrial production and education.
- Within budget constraints, continue to make funding for nanotechnology R&D a priority and seek to reduce rejection rates for proposals in nanotechnology so that they are comparable to programs in other R&D areas.
- Focus on specific areas of opportunity in which the NNI encourages R&D and capacity building, based in part on scientific community input from NNI workshops. Examples of such areas include:
  - Integration of physical and biological sciences
  - New instrumentation and tools for advancing nanotechnologies
  - Development of unifying tools for modeling, simulation, and visualization
  - Science of self-assembly
  - New approaches to the fabrication and operation of active nanostructures
  - Collective effects in assemblies and systems of nanostructures
  - Nanoscale manufacturing approaches including R&D on scale-up, reproducibility, process control, and integration into useful devices and systems
- Establish focused R&D objectives within each of the program component areas of the initiative. Develop interagency collaborative projects and partnerships with industry in order to meet these objectives.
- Initiate programs to foster creation of scientific and engineering platforms for precompetitive applications of nanotechnology. Examples of such platforms include nanotubes for integration in electromechanical and electronic devices; dendrimers for chemical, pharmaceutical and construction applications; and modular components for nanomanufacturing.
- Promote awareness of, and engagement in, international R&D activities by U.S.-based researchers. Strategies towards this end include extension of international student and postdoctoral exchange programs, support for international benchmarking activities, sponsorship of U.S. participation in international nanotechnology conferences, and attention to visa issues that are affecting participation in international exchanges.

GOAL 2: FACILITATE TRANSFER OF NEW TECHNOLOGIES INTO PRODUCTS FOR ECONOMIC GROWTH, JOBS, AND OTHER PUBLIC BENEFIT

In order to achieve the full benefit of the results of NNI-funded R&D, it is important to transition ideas into products. Technology transfer can occur via various pathways, including hiring of recent graduates and licensing of intellectual property resulting from Federally funded research. A primary aspect of all technology transfer is interaction among those who are performing R&D and those who manufacture and sell goods and services. The NNI plans to further its use of multiple avenues, including policy approaches, to facilitate successful nanotechnology commercialization.

Current Activities

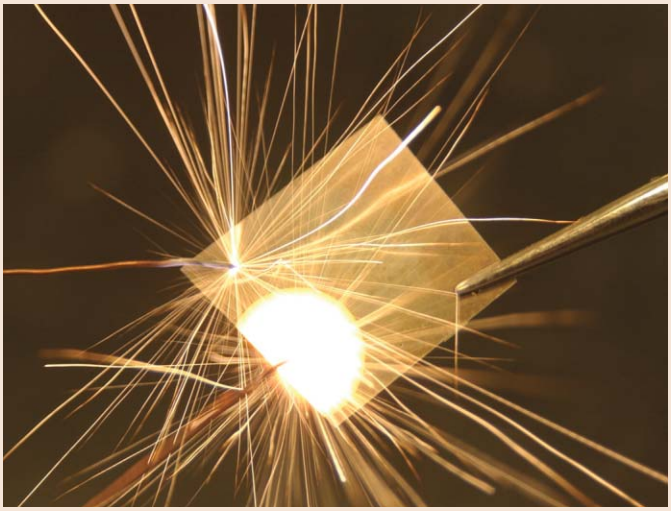
The NNI is using a range of approaches to support the transfer of nanotechnology discoveries from the laboratory to commercial use and public benefit. These approaches include the following:

NNI Facilitates Technology Transfer and Commercialization

Forming strong and thermally conductive bonds between different materials and components is a tricky process, but one of great commercial importance. For example, electronics manufacturers need to attach aluminum or copper cooling fins to high-performance microprocessor chips to conduct heat away from the chips and keep them from overheating. To enable the best heat removal and thereby the best chip performance, manufacturers would like to attach the cooling fins with conductive metallic solders. However, standard soldering processes heat up the entire chip and fin assembly and the associated high temperatures can damage the chip. Consequently, most cooling fins are attached to chip packages with adhesives or greases, but these materials do not conduct heat as well as metallic solders. Their limited ability to transmit heat to the cooling fins constrains the performance of the newest high-speed, high-density chips.

Now nanotechnology researchers have developed nanostructured foils that heat only the immediate surfaces of the components to be bonded, thereby avoiding thermal damage. The foils consist of thousands of alternating 10- to 20-nanometer thick layers of nickel and aluminum. The foils won't self-ignite, but when activated by an electrical pulse or laser, the nickel and aluminum react to form an alloy. This releases considerable heat in a carefully confined region. The inventors have subsequently formed a company, Reactive NanoTechnologies, which is commercializing the bonding foils. A broad array of customers, from computer chip and circuit board makers to aerospace manufacturers, are enthusiastic about this new bonding method.

The Reactive NanoTechnologies story shows how entrepreneurs can transfer technology developed through Federally funded research to the private sector. The underlying research was carried out at Lawrence Livermore National Laboratory and Johns Hopkins University, with support from several agencies participating in the NNI. Reactive NanoTechnologies was formed in 2001 to commercialize the resulting NanoFoil™ technology. To help bring its products to market, the company has secured venture capital funds, Phase I and II SBIR awards from the National Science Foundation and the Army Research Laboratory, and a NIST Advanced Technology Program award.



Courtesy Reactive NanoTechnologies

- Establish NSET industry liaison groups with various commercial sectors to promote exchange of information on NNI research programs and industry needs that relate to nanotechnology. Such activities are underway with the semiconductor/electronics and the chemical industries and are in development with the pharmaceutical and automotive industries.
- Support meetings at which researchers from academia, government, and industry exchange information on results and possible applications.
- Foster interaction among industry, academic, and government researchers through the establishment or support of user facilities that are available to researchers from all sectors. Examples include the existing NSF-funded National Nanofabrication Infrastructure Network (NNIN) and a suite of DOE-funded Nanoscale Science Research Centers (NSRCs), each with a specific focus, to be collocated at DOE laboratories across the country.
- Require that all NSF-funded Nanoscale Science and Engineering Centers (NSECs) include industry partners. Such associations allow industry to communicate its needs at an early stage and enhance the likelihood that new ideas will ultimately be developed and commercialized.
- Utilize the agency-run Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs to support early-stage nanotechnology-based solutions.
- Participate in standards development activities, including the American National Standards Institute (ANSI) Nanotechnology Standards Panel (NSP) established in September 2004. The present Director of the National Nanotechnology Coordination Office (NNCO) is the Government co-chair of the NSP. Areas of interest for standardization in nanotechnology include, for example, nomenclature and terminology, materials, metrology, and testing procedures.

Plans

To facilitate the transfer of NNI-developed nanotechnology for economic and public benefit, the NNI plans to continue and, where appropriate, expand the activities and approaches described above.

Further strategies in support of this goal include the following:

Industrial Outreach

- Encourage use of NNI-supported user facilities by businesses that do not otherwise have access to the advanced instrumentation and expertise resident therein. Emphasize that businesses may protect proprietary information that is created through use of such facilities if they reimburse the associated costs.
- Expand NSET's industry liaison activities to sectors beyond those already engaged. Such activities establish channels for exchange of information and can lead to other partnerships between Federal agencies and industry representatives.
- Continue to fund multidisciplinary research teams that include industry and university researchers through programs such as NSF's Grant Opportunities for Academic Liaison with Industry (GOALI), Nanoscale Science and Engineering Centers (NSECs), Partnerships for Innovation (PFI), and Industry/University Cooperative Research Centers (I/UCRC); NASA's University Research, Engineering and Technology Institutes (URETI); and the DOD University Affiliated Research Centers (UARCs).
- Encourage exchange of researchers between universities and industry to allow university personnel to spend time in industry labs and vice versa.
- Promote greater utilization of the agency-run SBIR and STTR programs to facilitate commercialization of nanotechnology by the following means:
  - Encourage agencies participating in the NNI to have components of their SBIR and STTR programs focused on nanotechnology topics, and in particular on nanomanufacturing. Such efforts are consistent with Executive Order 13329, in which the President gives high priority to manufacturing-related R&D within the SBIR and STTR programs.
  - Facilitate use of NNI-supported user facilities by small businesses that seek and receive SBIR and STTR grants and contracts.

Manufacturing Research

- Establish one or more centers focused on nanomanufacturing research, as called for in the Act. Where appropriate, do so via collaborative efforts among existing Federal agencies, programs, and offices with interests in manufacturing, e.g., DOD (including the ManTech program), NSF, and NIST.
- Support R&D focused on pre-competitive nanomanufacturing issues, including scale-up, reproducibility, and control of manufacturing processes.
- Coordinate with the NSTC Manufacturing Interagency Working Group (IWG), which has identified nanomanufacturing as a focus area for Federal manufacturing R&D activities.

Additional Activities

- Engage with regional, state, and local nanotechnology initiatives to facilitate economic development and exchange of information, through mechanisms such as workshops and electronic means.
- Consider new mechanisms to encourage technology transfer via licensing of intellectual property generated by NNI-funded research. Such mechanisms include forming of consortia among universities and other research institutions for purposes of pooling intellectual property and/or creating simplified or uniform technology transfer procedures.
- Support the U.S. Patent and Trademark Office's efforts to provide adequate protection to inventors and to encourage new technology development and commercialization of nanotechnology, including efforts to establish a nanotechnology classification hierarchy identifying patents directed to nanotechnology inventions.
- Provide and coordinate input to the Departments of Commerce, State, Defense, and Homeland Security with respect to the relationship between nanotechnology and policies on export/import restrictions, militarily critical technologies, and visa controls.
- Engage in international collaborations, workshops, conferences, and other activities in order to leverage the advances made worldwide for mutual economic and public benefit.

GOAL 3: DEVELOP EDUCATIONAL RESOURCES, A SKILLED WORKFORCE, AND THE SUPPORTING INFRASTRUCTURE AND TOOLS TO ADVANCE NANOTECHNOLOGY

A well-educated citizenry, a skilled workforce, and a supporting infrastructure of instrumentation, equipment, and facilities are essential foundations of the initiative. Nanoscale science, engineering, and technology education can help to (1) produce the next generation of researchers and innovators, (2) provide the workforce of the future with the math and science education and technological skills they will need to succeed, and (3) educate a citizenry capable of making well-informed decisions in an increasingly technology-driven society. The NNI utilizes a variety of approaches to address this need for nanotechnology-related education at all levels and for all ages.

Equally important to the goal of supporting public education and the human resource infrastructure is that of supporting the necessary physical infrastructure. The Federal Government maintains a host of user facilities outside the NNI that nevertheless support nanoscale R&D. Examples include the high intensity X-ray and neutron facilities run by DOE, NSF, and NIST. A role of the NNI is to develop additional infrastructure specifically addressing the needs of the nanotechnology research community. The cost of such facilities is out of reach for many businesses and academic institutions, but Federal funding can make these state-of-the-art research capabilities accessible to researchers based on merit review.

Current Activities

Education

Since FY 2001, the NNI has built a substantial education program focused on nanoscience and nanotechnology for K-12, university, and vocational students, and for the public. In addition, the NNI is establishing a geographically distributed physical infrastructure that provides access to state-of-the-art facilities and expertise for researchers from academia,

industry, and government. Ongoing efforts in both the education and infrastructure areas include the following:

- Provide hands-on training of undergraduates, graduate students, and postdoctoral researchers at universities, Federal laboratories, and other research institutions through the broad research program described under Goal 1.
- Via participating agencies, award funding directly to students for fellowships and traineeships that give recipients flexibility in choosing areas of research, especially those that cross multiple disciplines.
- Support development of educational programs aimed at training technicians to meet the growing demand from industry as nanotechnology applications move into more products and services. Such programs are implemented at community colleges and other institutions that emphasize development of job-related skills and knowledge.
- Bring nanoscience concepts into education for students at all ages. Existing programs include:
  - NSF's Research Experience for Teachers and Research Experience for Undergraduates, reaching thousands of students and educators annually
  - NSF's Nanoscale Science and Engineering Education, including Nanotechnology Undergraduate Education grants supporting course development
  - Educational activities occurring through DOE laboratories, such as the "Nano*High" effort at the Lawrence Berkeley National Laboratory in California — a series of free Saturday morning lectures for high school students of all interests and teachers of all subjects
- Support development of science center and museum exhibits, video productions, and other approaches to learning outside of formal educational institutions.

Infrastructure

- Establish and maintain geographically distributed user facilities to provide all researchers access to advanced instrumentation for fabrication, characterization, modeling, and simulation of nanoscale and nanostructured materials, devices, and systems. At present, the NNI supports the following such facilities:
  - Five Nanoscale Science Research Centers (NSRCs) that are under development and will be collocated with existing major facilities at DOE laboratories across the country. Upon completion, the NSRCs will be operated as user facilities that are available to all researchers on a merit-reviewed basis.
  - The National Nanotechnology Infrastructure Network (NNIN) comprising facilities at 13 partner universities aimed at providing fabrication and characterization facilities, instrumentation, and expertise.
  - The Network for Computational Nanotechnology (NCN) consisting of seven universities that together support computational research, as well as education and modeling and simulation tools that can be accessed via the web.
- Support additional infrastructure within the Federal laboratory enterprise dedicated to nanotechnology R&D, including the nanoscience facility at the Naval Research Laboratory and portions of the Advanced Measurement Laboratory at NIST.

Plans

Education

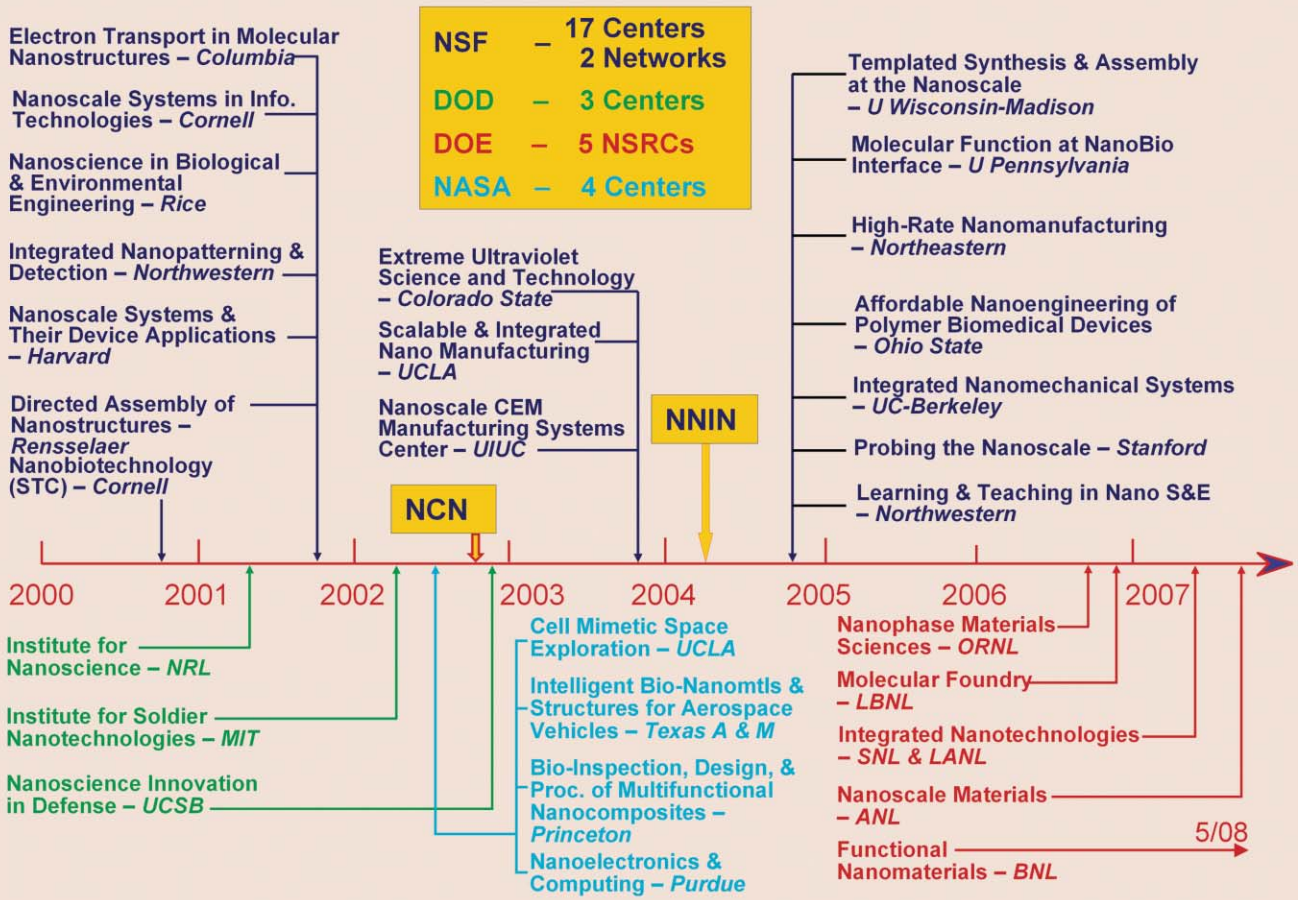
The NNI will continue ongoing activities that foster multidisciplinary education, teacher training, and development of curricula and instructional materials. The NNI also will explore additional mechanisms to facilitate training in advanced nanotechnology R&D and to support nanotechnology industry needs. Components of this effort include the following:

- Taking advantage of existing programs and exploring new partnerships to bring more students and teachers into research laboratories. Bringing together nanotechnology researchers with education researchers and teachers will provide mutual benefits by strengthening educational programs and providing fresh research perspectives.
- The nation's first Center for Learning and Teaching in Nanoscale Science and Engineering (NCLT) will be created with a recent five-year, $15 million grant from NSF. The center will develop scientist-educators at the middle-school, high-school, and

NNI Develops Research Centers and Infrastructure

The NNI already has developed a substantial network of research centers, user facilities, and related infrastructure throughout the United States. Since the NNI's inception in 2001, NSF, DOD, and NASA have established 24 research centers. Five DOE user facilities are under construction, with interim operational capability online already at some of these facilities. NSF has established a 13-university network of user facilities, the National Nanotechnology Infrastructure Network (NNIN), as well as the 7-university Nanotechnology Computational Network (NCN). In 2004, the total number of users of both the NCN and NNIN facilities and expertise exceeded 6300. The NNI centers, user facilities, and infrastructure support all of the NNI goals outlined in this strategic plan.

NNI Centers and User Facilities



undergraduate levels who can introduce nanoscience and nanoengineering concepts into schools and undergraduate classrooms. It will also serve as a national clearinghouse for curricular materials, instructional methods, and activities in nanotechnology education.

- Promoting partnerships between industry, education and training providers, and the Federally funded workforce system to ensure that nanotechnology firms have access to the highly skilled workers they need, and that workers have access to training programs that prepare them for careers in industry. The President's Jobs for the 21st Century initiative will ensure that local industry collaborates with local community colleges to meet these needs.

Infrastructure

Construction of some of the major user facilities mentioned above is ongoing and will continue through at least 2008. Operations of these facilities for the benefit of the nanotechnology community and continued development of infrastructure capabilities are key components of NNI plans.

- Develop specific programs to ensure ongoing support for existing infrastructure and centers. This effort will involve funding for (a) recapitalization of existing facilities and equipment, (b) scientific and technical staff expertise for their support, and (c) other operational costs.
- Maximize awareness and utilization of infrastructure resources. The NNI will initiate the compilation of data on U.S. Government-supported user facilities and instrumentation and make that information readily accessible to the nanotechnology research community at the NNI website, www.nano.gov. This data will be valuable in setting detailed strategies for further investment.
- Create an infrastructure that facilitates use of instrumentation and equipment from distant locations. The first steps of true tele-operation are already taking place as the most advanced instrumentation for imaging, characterization, and fabrication at the nanoscale increasingly requires that operators be remote from the equipment itself in order to minimize interference to the instruments due to presence of human operators, e.g., from thermal coupling, acoustic and/or vibration transmission, and bacterial or dust contamination.
- Leverage Federal support of large R&D facilities and projects by partnering with industry, states, private foundations, and international entities.
- Establish a facility specifically aimed at providing support for the use of nanotechnology for prevention, diagnosis, and treatment of cancer. This activity is getting underway through the NIH National Cancer Institute's formation of the Nanotechnology Characterization Laboratory (NCL). The NCL will help cancer researchers from academia, industry, and government accelerate regulatory review of nanomaterials or devices and translate these devices from research labs into the clinical realm.

GOAL 4: SUPPORT RESPONSIBLE DEVELOPMENT OF NANOTECHNOLOGY

Responsible development of nanotechnology means that the Federal Government not only supports the efforts described in NNI Goals 1 through 3 above, but at the same time addresses the various societal dimensions of the new technologies. Societal dimensions include a diverse range of subjects, such as access to benefits arising from nanotechnology, effects on the labor pool, changes in the way medicine is practiced, the impact of manufacturing locally at the point of need, concerns regarding possible health or environmental effects, and privacy concerns arising from distributed nanotechnology-based sensors. Responsible development of nanotechnology also means that the Federal Government establishes channels of communication, providing information to and seeking input from the public regarding the Federal nanotechnology program. Such communication allows the public and the Government to make well-informed decisions and builds trust among all stakeholders. Perceptions and acceptance of new technology are critical in the realization of economic and other societal benefits. Responsible development of nanotechnology further involves working with the international scientific community on areas of nanotechnology research and its societal dimensions that are of mutual interest.

For purposes of this plan, responsible development of nanotechnology has been divided into two categories: (1) environment, health, and safety implications, and (2) ethical, legal, and all other societal issues. Recognizing that technological innovations can bring both benefits and risks to society, the NNI has made research on and deliberation of these two areas a priority.

Current Activities

Environment, Health, and Safety Implications

The NNI supports a broad spectrum of research to evaluate the environmental, health, and safety impacts of nanotechnology. The level of NNI support for this research has increased with the discovery of new nanostructures and nanomaterials and the

development of new nanotechnology products. The NNI is continuing to:

- Study potential health risks of nanomaterials. Focused efforts are being pursued by six Federal agencies: the National Institute of Environmental Health Sciences (NIEHS, part of NIH, under the auspices of the National Toxicology Program), NIOSH, EPA, DOD, DOE, and NSF. In addition, NIST is supporting this work through the development of relevant standards.
- Facilitate communication among the member agencies; identify and prioritize research needed to support regulatory decision-making; and promote better communication among the Federal Government, industry, and researchers at universities and other institutions. These activities are coordinated by an NSET subgroup, the Nanotechnology Environmental and Health Implications Working Group (NEHI WG), with membership from agencies that support nanotechnology research as well as those with responsibilities for regulating nanotechnology-based products.
- Engage in international dialogue on environmental, health, and other societal issues. This effort was initiated at an international workshop sponsored by NSF in 2004, which resulted in a joint declaration by participants from 25 countries and the European Union supporting responsible development of nanotechnology.
- Conduct research on the fate and transport of manufactured nanomaterials in the environment and development of techniques to evaluate the full life cycle of nanomaterials.

NNI Addresses Potential Human Health and Environmental Impacts

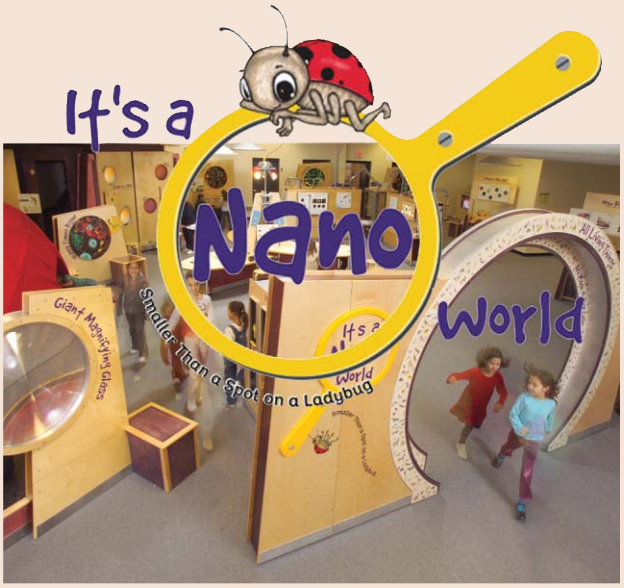
A number of Federal agencies, including DOE, DOD, EPA, NIH, NIOSH, and NSF, support research related to environmental and health aspects of nanomaterials. In particular, a broad program is underway within the National Toxicology Program (NTP), an interagency program within HHS. The NTP is addressing potential human health hazards associated with the manufacture and use of nanoscale materials. This research aims to place the toxicity of nanomaterials in perspective relative to other better known and better understood materials.

The program is starting with *in vivo* rodent toxicology studies using the most commercially important nanoscale materials as model systems. Initial studies were designed with an eye to extending the findings to guide the development of new manufactured nanomaterials. They include evaluation of:

- Size-dependent and surface coating-dependent disposition of semiconductor quantum dots when applied to the skin, ingested, or instilled into the respiratory tract
- Toxic effects of carbon nanotubes or fullerenes instilled into the respiratory tract compared to the effects of inhalation exposure
- Role of particle core and surface composition in the immunotoxicity of quantum dots, nanotubes, and fullerenes
- Dermal penetration and phototoxicology of nanoscale metal oxide particles, such as titanium dioxide used in sunscreens

NNI-Funded "NanoWorld" Displayed at Epcot

Because 120 million people visit U.S. science museums and centers each year, the NNI supports exhibits as an effective means of public outreach. The largest nanotechnology exhibit to date, "It's a NanoWorld," drew nearly 800,000 visitors at Innoventions at Epcot Center in Lake Buena Vista, Florida during 2004.



Courtesy Cornell University

Aimed at an elementary school audience, the 3,000 square-foot exhibit was funded by the National Science Foundation's Informal Science Education program and developed by Main Street Science, the education program at Cornell University's Nanobiotechnology Center; the Ithaca, N.Y. Sciencenter; and Painted Universe of Lansing, N.Y. Now on view at the HealthSpace in Cleveland, Ohio, the exhibit also is scheduled for stops in Michigan, Texas, and South Carolina. The successful collaborators have received additional NSF support for development of a new exhibition that will be called "Too Small To See." The exhibition will be targeted to ages 8 to 13 and adults and will travel to large and small locales nationwide. For more on "It's a NanoWorld," see http://www.itsananoworld.org/.

Ethical, Legal, and Other Societal Issues

Current NNI-supported research aimed at assessing the societal implications of nanotechnology includes the following activities:

- Support efforts to create a variety of opportunities for a broadly inclusive interdisciplinary dialogue on nanotechnology.
- Assess and analyze public understanding of, and attitudes toward, nanotechnology. A component of this is research on effective means to raise awareness of nanotechnology and obtain input from the general public.
- Analyze nanotechnology impacts on economic growth, standard of living, and competitiveness.
- Incorporate research on societal implications at some university-based nanotechnology centers. Such activities ensure that development takes place with an awareness of the societal impact of new technology.

Plans

Environment, Health, and Safety Implications

- As necessary, expand support for research into environmental and health implications of nanotechnology. NNI-funded research will (1) increase fundamental understanding of nanoscale material interactions at the molecular and cellular level through *in vitro* and *in vivo* experiments and models; (2) increase fundamental understanding of nanoscale materials interactions with the environment; (3) increase understanding of the fate, transport, and transformation of nanoscale materials in the environment and their life cycles; and (4) identify and characterize potential exposure, determine possible human health impact, and develop appropriate methods of controlling exposure when working with nanoscale materials.
- Assist in establishing and communicating effective procedures for working safely with nanomaterials. In collaboration with the NEHI working group,

NIOSH will be issuing guidelines in 2005 for developing safe working practices when producing and handling nanoscale materials. NIOSH and other NNI departments and agencies will distribute these guidelines to the research, business, emergency response, and related communities and will post them publicly on the NNI and NIOSH websites.

- Coordinate with the Health and the Environment Subcommittee of the NSTC Committee on Science and other appropriate interagency subcommittees and working groups.

Ethical, Legal, and Other Societal Issues

- Foster and encourage forums for dialogue with the public and other stakeholders. Such forums include museums and other science centers, various programs organized by NNI-funded research centers, the USDA extension program, and other agency outreach mechanisms.
- Create and distribute new informational materials about nanoscience and nanotechnology to better communicate with the broad public. Periodic measurements of public perceptions of nanotechnology will provide important feedback to the NNCO and agencies, as well as to the scientific community and policy makers.
- Support research on societal dimensions of nanotechnology development. Key research areas include economic, ethical, legal, and cultural implications, as well as implications for science and education, quality of life, and national security. Some examples of research to be funded include identification and assessment of:
  - Education and workforce development needs
  - Additional means of effective public engagement on technology issues
  - Barriers to adoption of nanotechnology in commerce, healthcare, or environmental protection
  - Ethical issues in the selection of research priorities and applications
- As called for by the Act, establish a center for nanotechnology research related to societal implications. The call for proposals for a Center for Nanotechnology in Society was issued in August 2004 by NSF. It specifies that the chosen center is to formulate a long-term vision for addressing societal, ethical, environmental, and education concerns; involve partners or affiliates to collaborate on topics related to responsible development of nanotechnology; include plans to involve a wide range of stakeholders; and develop a clearinghouse for information on communicating about nanoscience and nanotechnology and engaging the public in meaningful dialogue.

PROGRAM COMPONENT AREAS

Program Component Areas (PCAs) 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 relate to areas of investment that are critical to accomplishing those goals. These areas cut across the interests and needs of the participating agencies and indicate where advancement 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) and 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. The seven PCAs are defined as follows:

- **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.

- **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.

- **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.

- **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.

- **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.

- **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.

- **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 impacts of nanotechnology development and risk assessment of such impacts

- Education-related activities, such as development of materials for schools, undergraduate programs, technical training, and public outreach
- Research directed at identifying and quantifying the broad implications of nanotechnology for society, including social, economic, workforce, educational, ethical, and legal implications

Individual PCAs may encompass basic research through application-oriented efforts, including experimental, theoretical, modeling, and simulation approaches. There is a gradation within the PCAs in the scale or level of organization, ranging from fundamental nanostructure phenomena, through nanomaterials, devices, and systems, to tools and instrumentation, and finally to manufacturing. The last two PCAs listed above are different in nature, in that they provide for state-of-the-art research facilities and for addressing societal implications.

The PCAs as outlined in this plan represent the principal areas that are the focus of the NNI today. These areas are broad and are expected to continue to adequately describe the activities within the NNI for the next several years.

The NNI is first and foremost an R&D program, and therefore, not surprisingly, all of the PCAs support the first NNI goal listed in the previous chapter, that is, the maintenance of a world-class nanotechnology R&D program. In fact, all of the PCAs are related to some extent to each of the overarching NNI goals. The matrix in Table 1 qualitatively indicates the magnitudes of these relationships. Note that the activities in one or more PCAs are critical to making progress towards each goal.

Table 1. Relationship of the Program Component Areas to the Overarching NNI Goals

Program Component Areas:	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
Fundamental Nanoscale Phenomena and Processes	critical to goal	secondary relevance	primary relevance	secondary relevance
Nanomaterials	critical to goal	secondary relevance	secondary relevance	secondary relevance
Nanoscale Devices and Systems	primary relevance	critical to goal	secondary relevance	secondary relevance
Instrumentation Research, Metrology, and Standards for Nanotechnology	secondary relevance	critical to goal	secondary relevance	secondary relevance
Nanomanufacturing	secondary relevance	critical to goal	primary relevance	primary relevance
Major Research Facilities and Instrumentation Acquisition	primary relevance	primary relevance	critical to goal	secondary relevance
Societal Dimensions	secondary relevance	secondary relevance	primary relevance	critical to goal

critical to goal
primary relevance
secondary relevance

In addition to their relationship to the NNI goals, the PCAs are strongly correlated with the missions of the agencies and departments participating in the NNI. Table 2 shows for each participating agency (as of FY 2005) which PCAs have the strongest relationships to the agency's mission, interests, and needs. For agencies with budgets for nanotechnology R&D (shaded in Table 2), the strength of the relationship shown in Table 2 correlates with the level of investment. For those agencies that do not have nanotechnology R&D budgets (unshaded in Table 2), there are nevertheless connections with agency missions, as reflected in the table. For example, the FDA is particularly interested in the development of nanotechnology devices for medical use, as well as any health implications of materials that may be incorporated into products for which the agency has regulatory authority, such as cosmetics or food additives.

Table 2. Relationship between PCAs and NNI Agency Missions, Interests, and Needs

● - Primary ☐ - Secondary

Shading indicates agencies with budgets for nanotechnology R&D in FY 2005.

	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
CPSC	☐	☐	●	●			●
DHS	●		●	●		☐	
DOC (BIS)	☐	●	●	●	☐		
DOC (NIST)	☐	☐	☐	●	●	☐	☐
DOC (TA)	☐	☐	☐	☐	●	☐	●
DOC (USPTO)		●	●	●	●		
DOD	☐	●	●	☐	●	☐	☐
DOE	●	●	☐	☐	☐	●	☐
DOJ			●				
DOS							●
DOT	●	☐	●		●		
DOTreas		●	●				
EPA	☐	●	●	☐	●		●
HHS (FDA)		☐	●				●
HHS (NIH)	●	☐	●	☐	☐		☐
HHS (NIOSH)		☐			☐		●
IC	☐	●	●		☐		☐
ITC		●	●		●		●
NASA	☐	●	●		☐	☐	
NRC			●				
NSF	●	●	☐	☐	●	●	●
USDA	☐	●	●		☐		●

4. CROSS-CUTTING AREAS OF APPLICATION

The original implementation plan for the NNI identified nine "grand challenge" areas, corresponding to a variety of application areas in which nanotechnology was expected to have a significant impact. Some of the grand challenge areas were very broad (e.g., Nanomaterials by Design), whereas others were more specific (e.g., Chemical-Biological-Radiological-Explosive Detection and Protection). The plan described herein is organized somewhat differently, focusing on the overarching goals and the investment areas. These PCAs underlie virtually all the former grand challenge areas. Although the plan no longer refers explicitly to grand challenge areas, it recognizes the strong interest and support among the participating agencies for developing nanotechnology applications that address agency missions and needs. For example, nanomaterials research may target the creation of composites for lightweight structures that meet the requirements of certain aerospace applications. Research on fundamental nanoscale processes may address catalysis for energy conversion. Nanoscale sensor devices may enable *in vivo* detection of markers for a specific disease or detection of chemical or biological threats.

Mission-oriented agencies in the NNI, in particular, seek nanotechnology applications that will address their individual requirements. The following list, although not comprehensive, includes areas of application that relate to agency missions, national needs, and major industry sectors in which nanotechnology can have an impact. One or two agencies have a particularly strong connection to each specific application area and are therefore indicated by bold type as primary participants for that area. The relationships between agencies and application areas are summarized in Table 3, which follows the text descriptions.

Aerospace

High strength, low weight, multifunctional materials to improve performance and reduce operational costs for aircraft and spacecraft. Faster, yet more compact, electronics that enable fully automated, self-guided unmanned air vehicles for reconnaissance and surveillance.

Agency Participation and Partnerships

DHS	Aviation security, UAV platforms, situational awareness
DOD	Surveillance, uninhabited combat platforms, augmented human performance
DOE	Efficient fuel usage, batteries and fuel cells, materials research
DOT	Aviation safety
IC	Novel robotic systems
NASA	Intelligent spacecraft, smart materials/devices, autonomous healthcare systems
NIH	Telemedicine diagnostics/surgery; in-body systems for diagnosis/therapeutics
NIST	Materials research, standards
NSF	New principles and architectures for devices and systems; generic science base

Agriculture and Food

Secure production, processing, and shipment of food products. Improved agricultural efficiency. Reduced agricultural waste through conversion of agricultural materials into valuable products.

Agency Participation and Partnerships

DHS	Sensors for chemical and biological threats to food and agriculture
DOD	Ration/water reliability; food preservation
DOJ	Microbial forensics for protection of food and agriculture
DOS	International food security
EPA	Run-off from crops and livestock
FDA	Safe food (human and animal); public health protection
NSF	Basic research on plant growth and food processing
USDA	Improved agricultural production and value without environmental detriment

National Defense and Homeland Security

Systems with the speed and capacity to enable command, control, communications, surveillance, reconnaissance, and information dominance. Automation and robotics with sufficient decision-making capabilities to minimize the exposure of warfighters and first responders to harm. Platforms and weapons with performance that is unquestionably superior to adversarial capability, yet which are affordable and easily maintained. Cost-effective aids for timely training of new recruits and other personnel, especially at remote sites.

Agency Participation and Partnerships

DHS Chemical, biological, radiation, and explosives detectors; first responder protection
DOD Materials for weapons and platforms; technology for information dominance
DOE System integration; lab-on-a-chip; radiological and explosives detection
DOJ Detection of and protection against chemical and biological agents; DNA analysis
DOS Diplomatic security; biometrics
DOT Explosives detection; advanced transportation security systems
EPA Hazardous material reduction and remediation
IC Chemical, biological, radiological, and explosives detection
NASA System integration; miniaturization; robotic systems
NIH Detection/treatment for chemical, biological, and radiological substances
NIOSH Hazardous material detection
NIST Chemical microsensors, single molecule measurement
NSF Broad-based science investment to prevent surprise; sensors and devices
USDA Secure agricultural production and food resources

Energy

Significant improvements made through tailored nanomaterials, for example, in solar energy conversion, transmission, and storage; thermoelectric converters; and high performance batteries and fuel cells. Control of corrosion, friction, and wear for reduced maintenance and energy consumption. Catalysts for energy-efficient manufacturing.

Agency Participation and Partnerships

DHS Reduction in weight and costs of detection systems
DOD Energetic materials for propulsion/explosives; compact, lightweight power sources
DOE All aspects of energy research, including catalysis, fuel cells, hydrogen
DOS Sustainable energy for development; energy security
EPA Energy from waste and alternative fuels
IC Nano-enabled advanced power systems
NASA Energy conversion and storage for space systems
NIST Materials research and characterization; standards
NSF Generic science base, including catalysis and energy conversion
USDA Biomass conversion for energy, chemicals, polymers, and industrial products

Environmental Improvement

Improved understanding of molecular processes that take place in the environment. Reduced pollution through the development of new "green" technologies that minimize manufacturing and transportation waste products. Better environmental remediation through more efficient removal of contaminants, especially ultrafine particles, from air and water supplies, and by continuous measurement and mitigation of pollution in large geographical areas.

Agency Participation and Partnerships

DHS Immediate chemical, biological, and radiological decontamination
DOE Remediation; waste containment; extraction of radionucleotides
DOS Global pollution prevention and mitigation
EPA Detection, remediation and prevention of environmental pollution
FDA Bio-environmental processes
NIOSH Detection, monitoring, and control of environmental pollution

NIST Standards; sensor development
NSF Nanoscale processes in nature; green manufacturing; nanomaterials dispersion
USDA Green agriculture and food processes

Information Technologies

Silicon-based semiconductor electronics today already have nanoscale (i.e., less than 100 nm) features. Continued increases in performance based on breakthroughs and implementation of even smaller scale technologies. Future devices, perhaps based on novel magnetic, spin, molecular, or quantum information approaches. Nanotechnology-based systems to improve computer speed, provide non-volatile random access memory, expand mass storage, reduce power consumption per unit operation, increase bandwidth for data transmission, and enable flexible, flat displays that are many times brighter than the displays of today.

Agency Participation and Partnerships

DHS Embedded radio frequency tags for tracking; communications for detectors
DOD Devices for communication, command, control, surveillance, and reconnaissance
DOE Nanoelectromechanical systems (NEMS); laboratory-on-a-chip; reduced power consumption devices
IC Molecular electronics; advanced communication systems
NASA Highly effective, miniaturized, low power devices for spacecraft
NIST Standards for measurement; manufacturing quality control
NSF Novel phenomena, processes, devices, and architectures; generic science base

Medicine and Health

Novel sensor arrays enabling inexpensive, rapid diagnosis in a doctor's office or at home for a range of conditions. New composite structures for superior bone and tooth implants. Targeted, highly effective treatment of diseases such as cancer and heart disease with reduced side effects.

Agency Participation and Partnerships

DOD Casualty care; monitoring warfighter physiology; performance enhancement
DOE Radiation effects; sensors; hard/soft matter interfaces
DOS Global health issues; epidemics and emerging infectious diseases
FDA Quality control; regulation of human and animal drugs, medical devices, biologics, food, cosmetics, and radiation-emitting electronic products
NASA Remote and autonomous medical care in space environments
NIH Therapeutics; diagnostics; regenerative medicine
NIOSH Associations between nanomaterials and biological activity; occupational health
NIST Standards; nanobioengineering; drug delivery systems
NSF Nanobioscience; nanobioengineering
USDA Animal production; food safety; food for enhancing health

Transportation and Civil Infrastructure

Automated systems that dramatically reduce accidents and lower costs of transporting goods. More efficient vehicles through the use of higher performance materials. Vehicles, bridges, and roadways that are far less expensive to build and maintain through use of composite material structures.

Agency Participation and Partnerships

DHS Transportation security; critical infrastructure protection
DOD Effective, fuel-efficient military platforms; infrastructure for rapid transportation
DOE Fuel efficiency; hydrogen economy
DOT Safe, affordable, efficient, and long-lived transportation infrastructure; vehicle safety sensors
EPA Reduced pollution and improved efficiency of transportation vehicles
NSF Basic research in civil infrastructure and transportation

Table 3. NNI Agency Participation in Cross-Cutting Applications

● - Primary participant ☐ - Secondary participant

Shading indicates agencies with budgets for nanotechnology R&D in FY 2005.

	DHS	DOC (NIST)	DOD	DOE	DOJ	DOS	DOT	EPA	HHS (FDA)	HHS (NIH)	HHS (NIOSH)	IC	NASA	NSF	USDA
Aerospace	☐	☐	☐	☐			☐			☐		☐	●	☐	
Agriculture & Food	☐		☐		☐	☐		☐	☐					☐	●
National Defense & Homeland Security	●	☐	●	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐	☐
Energy	☐	☐	☐	●		☐		☐				☐	☐	☐	☐
Environmental Improvement	☐	☐		☐		☐		●	☐		☐			●	☐
Information Technologies	☐	☐	●	☐								☐	☐	●	
Medicine & Health		☐	☐	☐		☐			☐	●	☐		☐	☐	☐
Transportation & Civil Infrastructure	☐		☐	☐			●	☐						☐	

5. MANAGEMENT STRUCTURE AND RESPONSIBILITIES

Interagency management of the NNI occurs within the framework 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 parts of the Federal science and technology R&D enterprise. Figure 1 is an organizational chart showing the various entities that play a role in the NNI and their relationships to each other. It includes not only the NSTC and its relevant subgroups, but also other government and non-governmental bodies that are engaged in the initiative. The roles of the various entities and their key relationships are described below.

NSET SUBCOMMITTEE

Under the NSTC Committee on Technology (CT), the Nanoscale Science, Engineering, and Technology (NSET) Subcommittee is the body that coordinates, plans, and implements the NNI. Whereas certain programs under the NNI are expected to fall within the mission of a single agency, others cross agency missions and benefit from active and sometimes broad interagency coordination. Recognizing that the NNI is focused on advances in both science and technology, the NSET Subcommittee formally reports to the CT but will also keep the NSTC Committee on Science informed of its activities.

As the active interagency coordinating body, the NSET Subcommittee establishes the goals and priorities for the NNI and develops plans, including appropriate interagency activities, aimed at achieving those goals. The Subcommittee promotes a balanced investment across all of the agencies, so as to address all of the critical elements that will support the development and utilization of nanotechnology. The Subcommittee exchanges information with academic, industry, and state and local government groups that are conducting research on and using nanotechnology.

WORKING GROUPS UNDER THE NSET SUBCOMMITTEE

A number of working groups exist under the NSET Subcommittee and are also shown in Figure 1. The subgroups are focused on areas that the Subcommittee recognizes will benefit from focused interagency attention and activity: environmental and health implications of nanotechnology, liaison activities with industrial and professional groups, and nanomanufacturing.

Nanotechnology Environmental and Health Implications Working Group (NEHI WG)

This subgroup brings together representatives from agencies that support nanotechnology R&D and those with regulatory responsibilities to exchange information and identify research needed to support regulatory decision-making processes. The NEHI WG promotes communication regarding environmental and health implications among Federal agencies, researchers, and small and large companies.

Industry Liaison Working Group

This subgroup seeks to interact with representatives of industry sectors to establish channels by which the government agencies can provide information on their R&D activities and by which industry representatives (e.g., from trade associations and professional societies) can provide input regarding how the Federal investment in nanotechnology might best support pre-competitive R&D that addresses industry needs.

Nanomanufacturing Working Group

Recognizing that the establishment of a nanomanufacturing base in the United States will depend on coordinated activities among multiple agencies, the Subcommittee established the Nanomanufacturing Working Group. NSF, NIST, and DOD are particularly active in the area of nanomanufacturing.

- NSF has established three Nanoscale Science and Engineering Centers (NSECs) with a nanomanufacturing focus, and expects to establish another in FY 2005. Each multidisciplinary NSEC brings together researchers with a range of expertise from several institutes and departments, as well as industry partners. The centers not only emphasize nanomanufacturing research, but also address societal aspects of the new technologies and related educational needs.
- NIST's mission includes support for and development of advanced standards and measurement technologies. Such technologies are vital to the continued strength of U.S. technology-based industries. The competencies and state-of-the-art facilities brought to bear by NIST are especially valuable during the nascent stage of development of nanomanufacturing methods, systems, and processes.
- DOD's Manufacturing Technology (ManTech) Program supports the development of manufacturing capability and capacity, which is important to the Department's mission. As nanotechnology solutions for DOD requirements are developed, the ManTech Program is a likely mechanism through which the United States will address the manufacturing issues. In addition, under its Multidisciplinary University Research Initiative (MURI) program, the DOD plans to establish a center focused on nanomanufacturing issues relevant to transitioning nanotechnology-based products to military use.

These informal subgroups will be maintained for as long as they continue to benefit the NNI and facilitate interagency coordination activities. Additional subgroups may be formed, as appropriate.

NATIONAL NANOTECHNOLOGY COORDINATION OFFICE (NNCO)

To support the interagency coordination activities of the NSET, including its subgroups, the National Nanotechnology Coordination Office (NNCO) was established in 2001 by a memorandum of understanding among the eight agencies participating in the NNI at that time. The NNCO is funded by NSET Subcommittee agency contributions. The NNCO provides technical and administrative support to the NSET Subcommittee. In addition, it is chartered to serve as the point of contact on Federal nanotechnology activities, conduct public outreach, and promote transfer of the results of Federal nanotechnology R&D for commercial use and public benefit. The NNCO Director is detailed from a Federal agency to NSTC and is appointed by the White House Co-Chair of the NSTC Committee on Technology, in consultation with the Chair of the NSET Subcommittee. The NNCO Director reports to the White House Co-Chair of the CT. The NNCO Director is charged in the Act to arrange, on behalf of the NSET Subcommittee agencies, with the National Research Council of the National Academies to conduct a triennial review of the NNI and transmit the results of these evaluations to Congress.

EXECUTIVE OFFICE OF THE PRESIDENT

Participation in the NNI by relevant offices within the Executive Office of the President (EOP) helps ensure coordination and implementation of government-wide priorities. Since the inception of the NNI, the Office of Science and Technology Policy and the Office of Management and Budget have been active participants in the NSET Subcommittee.

OSTP is responsible for advising the EOP on matters relating to science and technology and, in general, supports coordination of interagency science and technology activities. OSTP administers the NSTC and is an active member of the NSET Subcommittee, providing EOP-level input on and support for various NNI activities.

OMB is responsible for coordinating with the agency budget offices to establish the nanotechnology R&D budget for planning and tracking purposes. Each year, as the President's Budget is prepared, OMB collects budget information regarding the total Federal investment in nanotechnology R&D. OMB will begin to collect information about agency investments within each PCA for FY 2006.

NON-GOVERNMENTAL BODIES

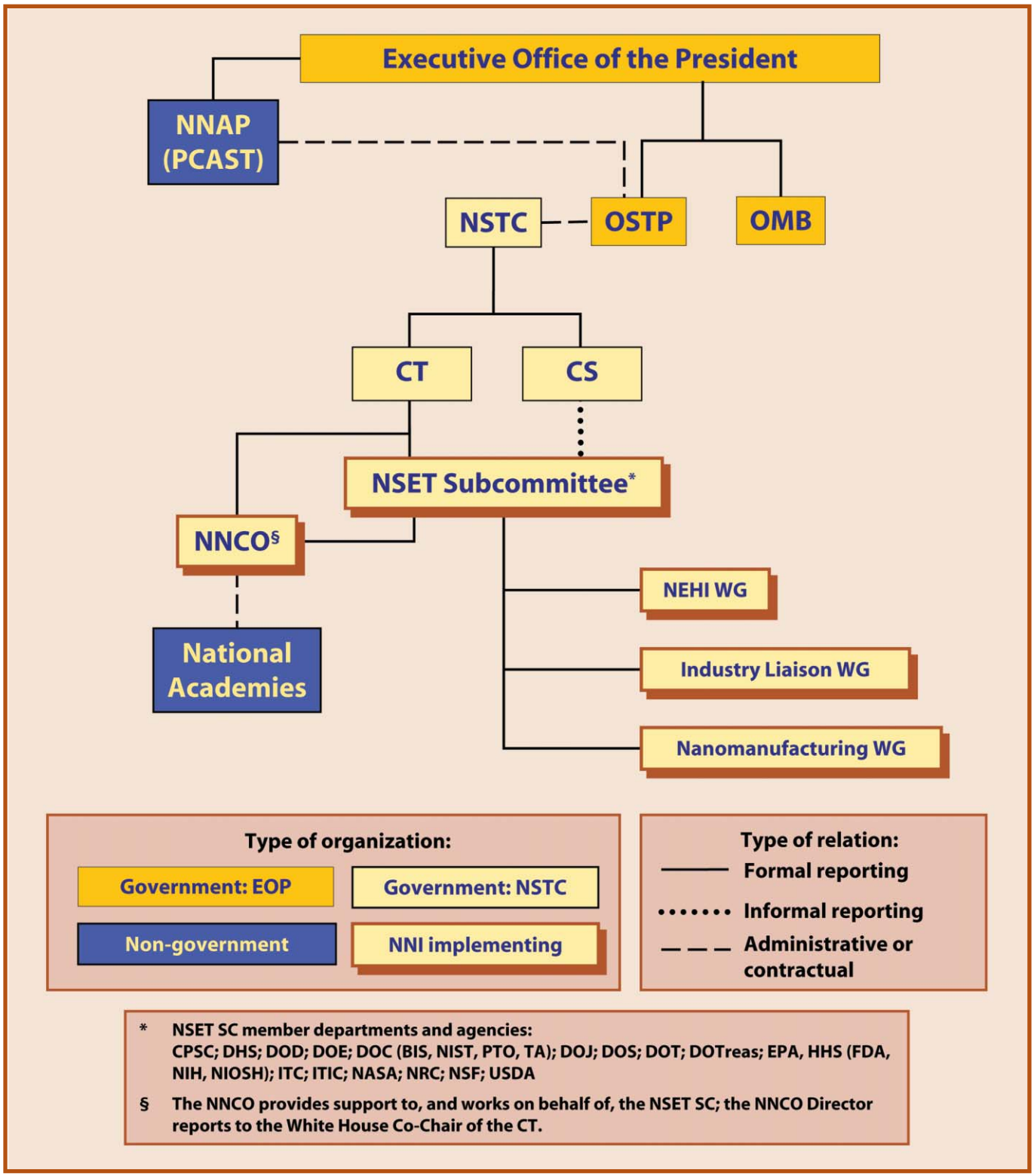
In addition to the NSTC, its subgroups, and other entities within the Executive branch of the Federal Government, two non-governmental but statutorily mandated entities are shown in Figure 1. They are the National Nanotechnology Advisory Panel (NNAP) and the National Research Council of the National Academies.

The NNAP is a Presidential advisory body created by the Act. In July 2004, the President's Council of Advisors on Science and Technology (PCAST) was designated by Executive Order as the NNAP. The Act calls for the NNAP to periodically assess the Federal nanotechnology R&D program and to report the results at least once every two years.

In addition to the biennial review by the NNAP, the National Research Council is to review the NNI on a triennial basis. The National Research Council is part of the National Academies and is a private, nonprofit institution that provides science, technology and health policy advice under a Congressional charter. The National Research Council is the principal operating agency of the National Academies in providing services to the government, the public, and the scientific and engineering communities. Topics to be included in each review are enumerated in the Act; the first review is to include two additional one-time assessments. Those one-time reviews are of "the technical feasibility of molecular self-assembly for the manufacture of materials and devices at the molecular scale" and "the need for standards, guidelines, or strategies for ensuring the responsible development of nanotechnology." The first review is due by June 3, 2005.

The NSET Subcommittee and the participating agencies will use the findings and recommendations of the NNAP and the National Research Council to progressively strengthen the NNI going forward.

Figure 1. Chart Showing Organizations with a Role in the NNI and Their Relationships



APPENDICES

APPENDIX A. GLOSSARY

Act	Public Law 108-153, the 21st Century Nanotechnology Research and Development Act
Agencies	Departments, agencies and commissions within the Executive Branch of U.S. Federal Government
ANSI	American National Standards Institute
BIS	Bureau of Industry and Security (Department of Commerce)
CPSC	Consumer Product Safety Commission
CS	Committee on Science of the NSTC
CT	Committee on Technology of the NSTC
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
EOP	Executive Office of the President
EPA	Environmental Protection Agency
FDA	Food and Drug Administration
GOALI	Grant Opportunities for Academic Liaison with Industry (NSF program)
HHS	Department of Health and Human Services
ITIC	Intelligence Technology Innovation Center
ITC	International Trade Commission
IC	Intelligence Community
I/UCRC	Industry/University Cooperative Research Centers (NSF program)
IWG	Interagency working group
ManTech	Manufacturing Technology (DOD program)
MOU	Memorandum of understanding
MURI	Multidisciplinary University Research Initiative (DOD program)
NASA	National Aeronautics and Space Administration
NCL	Nanotechnology Characterization Laboratory (National Cancer Institute)
NCLT	Center for Learning and Teaching in Nanoscale Science and Engineering (NSF Center)
NEHI	Nanotechnology Environmental and Health Implications (Working Group of the NSET Subcommittee)
NEMS	Nanoelectromechanical systems
NIH	National Institutes of Health (Department of Health and Human Services)
NIOSH	National Institute for Occupational Safety and Health (Centers for Disease Control and Prevention/Department of Health and Human Services)
NIRT	Nanoscale Interdisciplinary Research Team (NSF program)
NIST	National Institute of Standards and Technology (Department of Commerce)
NNAP	National Nanotechnology Advisory Panel
NNCO	National Nanotechnology Coordination Office
NNI	National Nanotechnology Initiative
NNIN	National Nanotechnology Infrastructure Network (NSF program)
NPAC	Nanotechnology Program Advisory Committee

NRC	Nuclear Regulatory Commission
NRL	Naval Research Laboratory
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 program)
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
PFI	Partnerships for Innovation (NSF program)
USPTO	U.S. Patent and Trademark Office (Department of Commerce)
SBIR	Small Business Innovation Research (multi-agency program)
SC	Subcommittee
STTR	Small Business Technology Transfer (multi-agency program)
TA	Technology Administration (Department of Commerce)
UARC	University Affiliated Research Center (DOD program)
UAV	Unmanned aerial vehicle
URETI	University Research, Engineering and Technology Institutes (NASA program)
USDA	U.S. Department of Agriculture
WG	Working Group

APPENDIX B. BIBLIOGRAPHY

National Science and Technology Council Publications

The following reports published by the NSET Subcommittee, after formal clearance by the National Science and Technology Council, serve as supporting documentation for the National Nanotechnology Initiative.

- *Nanotechnology: Shaping the World Atom by Atom.* 1999. Brochure explaining nanotechnology and its potential for the general public. http://www.wtec.org/loyola/nano/IWGN.Public.Brochure/
- *Nanostructure Science and Technology.* 1999. Worldwide study on status and trends. http://www.wtec.org/loyola/nano/
- *Nanotechnology Research Directions: IWGN Workshop Report.* 1999. Report of the first NNI Research Directions workshop. http://www.wtec.org/loyola/nano/IWGN.Research.Directions/
- *National Nanotechnology Initiative: The Initiative and its Implementation Plan.* 2000. First detailed implementation plan for the NNI. http://nano.gov/html/res/nni2.pdf
- *National Nanotechnology Initiative; Research and Development Supporting the Next Industrial Revolution.* 2003. Supplement to President's FY 2004 Budget. http://nano.gov/html/res/fy04-pdf/fy04-main.html

Related Agency Publications

- *Nanoscience and Nanotechnology: Shaping Biomedical Research.* 2000. Symposium Report by Bioengineering Consortium, National Institutes of Health. http://www.becon.nih.gov/nanotechsympreport.pdf
- *Societal Implications of Nanoscience and Nanotechnology.* 2001. NSF report on the September 2000 workshop of the same name, also published by Kluwer Academic Publishing, 2001. http://www.wtec.org/loyola/nano/societalimpact/nanosi.pdf
- *Nanoscale Science and Engineering for Agriculture and Food Systems.* 2002. Report Submitted to the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture. http://www.nseafs.cornell.edu/web.roadmap.pdf
- *Going Small for Big Advances: Using Nanotechnology to Advance Cancer Diagnosis, Prevention, and Treatment.* 2004. National Cancer Institute, National Institutes of Health. http://otir.nci.nih.gov/brochure.pdf
- *Nanotechnology in Heart, Lung, Blood, and Sleep Medicine, Executive Summary.* 2003. National Heart, Lung, and Blood Institute, National Institutes of Health, NHLBI Working Group. http://www.nhlbi.nih.gov/meetings/nano_sum.htm

Previous Outside Reviews of the NNI

- *Small Wonders, Endless Frontiers: Review of the National Nanotechnology Initiative.* 2002. National Research Council. http://nano.gov/html/res/smallwonder.html

APPENDIX C. LIST OF NNI-SPONSORED WORKSHOPS

The following is a list of workshops organized or supported by the agencies participating in the National Nanotechnology Initiative between 2001 and 2004 with the objective of gathering input for NNI strategic planning.

Workshops: Completed Reports

- *Nanotechnology: Opportunities and Challenges.* Regional Workshop of the National Nanotechnology Initiative hosted by the University of California at Los Angeles, September 2001. Los Angeles, CA. http://wtec.org/nanoreports/FinalUCLAnanoRpt0302.pdf
- *NSF-EC Workshop on Nanomanufacturing and Processing.* Summary Report from the National Science Foundation workshop, January 2002. San Juan, Puerto Rico. http://www.nsf.gov/mps/divisions/dmr/research/nsfec_workshop_report.pdf
- *From the Laboratory to New Commercial Frontiers.* A Regional Workshop of the National Nanotechnology Initiative hosted by Rice University, May 2002, Houston, TX. http://wtec.org/nanoreports/ACF64.pdf
- *Nanotechnology Innovation for Chemical, Biological, Radiological, and Explosive (CBRE): Detection and Protection.* Final report of the NNI Grand Challenge Workshop, May 2002. Monterey, CA. Murday, J., J. Baker, R. Colton, H.S. Gibson, M. Grünze, S. Lee, K. Klabunde, C. Martin, T. Thundat, B. Tatarchuk, and K. Ward. http://www.wtec.org/nanoreports/cbre/
- *Chemical Industry R&D Roadmap for Nanomaterials By Design: From Fundamentals to Function.* Final report of the Vision 2020/NNI Grand Challenge Workshop, Baltimore, MD, September / October 2002. Chemical Industry Vision 2020 Partnership. http://www.chemicalvision2020.org/nanomaterialsroadmap.html
- *Nanoscience Research for Energy Needs,* Report of the National Nanotechnology Initiative Grand Challenge Workshop, March 2004. Alexandria, VA. Hwang, R., and E. Williams, eds. http://www.sc.doe.gov/bes/reports/files/NREN_rpt.pdf

Workshops: Final Reports in Preparation

- *Buildings for Advanced Technology Workshop,* National Institute of Standards and Technology, Gaithersburg, Maryland, January 14-16, 2003. Overview available at http://www.nanobuildings.com/bat/overview/default.htm.
- *NNI Grand Challenge Workshop: Nanoscale Processes for Environmental Improvement,* Arlington, VA, May 8-10, 2003.
- *NNI Grand Challenge Workshop on Nanomaterials,* National Science Foundation, June 11-13, 2003.
- *National Nanotechnology Coordinating Office Interagency Research Meeting/Workshop — Nanotechnology and the Environment: Applications and Implications,* Arlington, VA, September 15-16, 2003. Summary available at http://es.epa.gov/ncer/publications/nano/index.html.
- *NNI Workshop on Regional, State, and Local Initiatives in Nanotechnology,* Washington, DC, September 30–October 1, 2003.
- *NNI Workshop on Nanobiotechnology,* Arlington, VA, October 9-11, 2003.
- *NNI Workshop on Societal Implications of Nanoscience and Nanotechnology,* National Science Foundation, Arlington, VA, December 3-5, 2003.

- *NNI Grand Challenge Workshop on Instrumentation and Metrology for Nanotechnology,* National Institute of Standards and Technology, Gaithersburg, MD, January 27-29, 2004.
- *NNI Grand Challenge Workshop on Nano-Electronics, -Photonics, and -Magnetics,* Arlington, VA, February 11-13, 2004.
- *NNI Workshop on Nanotechnology for Space Exploration,* Palo Alto, CA, August 24-26, 2004.
- *National Nanotechnology Initiative Research Directions II Workshop,* Washington, DC, September 8-10, 2004.

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