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Manipulating Molecules: The National Nanotechnology Initiative

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Summary

The Bush Administration has requested $849 million for nanotechnology research for FY2004, a 9.7% increase over FY2003. **(See Table 1.)** Nanotechnology is a newly emerging field of science where scientists and engineers are beginning to manipulate matter at the molecular and atomic level in order to obtain materials and systems with significantly improved properties. Ten nanometers is equal to one-ten thousandths the diameter of a human hair. Proponents of this technology argue that nanotechnology will lead to a new industrial revolution in the 21st century. Scientists note that nanotechnology is still in its infancy, with large scale practical applications10 to 30 years away. Congressional concerns center around coordination and priority setting for the NNI, whether the President's Council of Advisors on Science and Technology (PCAST) or an independent non-governmental experts should be used to conduct outside periodic reviews of the NNI, challenges associated with interdisciplinary research, and potential environmental and health concerns associated with the deployment of nanotechnologies. Both the House (H.R. 766) and Senate (S. 189) have introduced legislation that would establish the NNI in law This report will be updated as events warrant.

Introduction

For FY2004, the Bush Administration has designated the National Nanotechnology Initiative (NNI) as a multi-agency research initiative. As indicated in **Table 1,** the Administration is requesting $849 million for the NNI, a 9.7% increase over the FY2003 estimated funding level of $774 million. If Congress approves this requested increase, funding for the NNI will have doubled since FY2001. Nanotechnology is the creation and utilization of materials, devices, and systems with novel properties and functions through the control of matter atom by atom, or molecule by molecule. Such control takes place on a scale of a fraction of a nanometer to tens of nanometers. Ten nanometers is equal to one-ten thousandths the diameter of a human hair.

Academic and industry scientists working in this field contend that research in nanoscience will lead to revolutionary breakthroughs in such areas as medicine, manufacturing, materials, construction, computing, and telecommunications. For example, *Science* magazine designated scientists' and engineers' ability to build the first set of molecular-scale circuits as the scientific breakthrough of 2001. The magazine noted that when such circuits are wired to computer chip architectures this will result in incredible computing power in tiny machines.[1] Many scientists contend that breakthroughs in nanotechnology (or nanoscience as some researchers refer to it) will eventually lead to molecules replacing silicon on computer chips which in turn could result in computers that are billions of times faster than today's most sophisticated computers. Researchers are also studying ways to treat neurological disorders by developing silicon capsules that include nanopore screening membranes (18-25 nanometers wide) that allow the desired molecules to flow in and out while blocking the patient's antibodies from attacking the treated area. While both private sector and federally sponsored research in nanoscience has led to encouraging breakthroughs in the last couple of years, nanotechnology is still in its infancy. Most scientists contend that practical applications of this newly emerging science, such as the ones described above, could be 10 to 30 years away.

Nanotechnology and the Federal Role

All natural materials and systems establish their fundamental properties at the atomic and molecular scale. Consequently, the ability to control matter at those levels provides the means for tailoring the fundamental properties, phenomena, and processes exactly at the scale where the basic properties are determined. According to the Administration, in FY2004 the NNI will continue to focus on fundamental research in the following areas: 1) Research to enable efficient nanoscale manufacturing, and novel instrument for nanoscale measurements; 2) Nano-biological systems for medical advancements and new products; 3) Innovative nanotechnology solutions for detection or and protection from biological-chemical-radiological-explosive agents; 4) the education and training of a new of a new generation of workers for future industries; and 5) Partnerships and other policies to enhance industrial participation in the nanotechnology revolution.[2]

Once the NNI was established in 2000, the Nanoscale Science and Engineering and Technology (NSET) also was established as a subcommittee of the National Science and Technology Council's (NSTC) Committee on Technology. NSET serves as the coordinating body of the NNI with membership composed of representatives from the different departments and agencies participating in the initiative, as well as a representative from the Office of Science and Technology Policy. The NNI is built around five funding themes distributed among the agencies currently participating in the NNI. The agencies include the National Science Foundation (NSF), the Departments of Defense (DOD), Energy (DOE), Homeland Security (HLS), Agriculture (USDA), Justice (DOJ), the National Institutes of Health (NIH), the National Aeronautics and Space

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[1] *Molecules Get Wired*, Science Vol. 294, December 21, 2001. P. 2442-43.

[2] Fiscal Year 2004, Analytical Perspectives, Budget of the U.S. Government, p.177-78.

Administration (NASA), The National Institute of Standards and Technology (NIST), within the Department of Commerce, and the Environmental Protection Agency (EPA).

In October of 2000, the NSTC approved NSET's request to establish the National Nanotechnology Coordinating Office (NNCO). Besides being responsible for the day-to-day management of the NNI, the NNCO will assist the NSET committee with identifying funding priorities, establishing budgets, and evaluating current NNI activities. Below is a brief summary of the five major cross-cutting NNI themes with *estimated* funding levels for FY2003 as well as the proposed increases for each theme in FY2004.[3]

1. Fundamental Nanoscience and Engineering Research. *($248 million +$22 million)* Long term basic research is essential to establishing a fundamental knowledge of nanoscale phenomena. Research activities will focus on fundamental understanding and synthesis of nanometer-size building blocks with potential breakthroughs in areas such as materials and manufacturing, nanoelectronics, medicine and healthcare, environment and energy, chemical and pharmaceuticals industries, biotechnology and agriculture, computation and information technology, and national security. One of the fundamental challenges facing researchers is to try to control and manipulate matter at the ultimate frontier where, for example, as you move from 1 to 100 nanometers, the texture of atomic and molecular matter can suddenly change from soft, to hard, to brittle, and back to soft again without explanation.

Table 1. Estimated Funding for Nanotechnology FY2004

$ millions

	FY2001 Enacted	FY2002 Enacted	FY2003 Estimate	FY2004 Request
NNI Total	**422**	**697**	**774**	**849**
NSF	150	204	221	249
DOD	110	224	243	222
DOE	88	89	133	197
HHS (NIH)	39	59	65	70
NASA	20	35	33	31
DOC (NIST)	10	77	69	62
EPA	5	6	6	5
Dept. HLS. (TSA) [a]	0	2	2	2
USDA	0	0	1	10
Dept. of Justice	0	1	1	1

a. Transportation Security Administration

2. Grand Challenges. *($279 million + $24 million)* The second theme includes support for interdisciplinary research and education teams, including centers and

[3] For more details of the FY2003 NNI themes, see *National Nanotechnology Initiative*, *The Initiative and Its Implementation Plan*, Detailed Technical Report Associated with the Supplemental Report to the President's FY2003 Budget, June 2002, p. 46-86.

networks, that work on major long-term objectives. In the area of efficient energy conservation and storage one of the challenges is to understand how deliberate tailoring of materials at the nanoscale can lead to novel and enhanced functionalities of relevance in energy conversion, storage and conservation. Another long term challenge is to develop tools for modeling and simulating the broad range of manufacturing processes involving nanostructures thus allowing the processes to be better understood and optimized. Developing bio-nanosensor devices for biological threat detection is another nanotechnology opportunity that could foster efficient and rapid biochemical detection and mitigation in situ for chemical bio-warfare.

3. Centers and Networks of Excellence. *($124 million + $14 million)* To date, 15 centers of excellence (6 NSF, 4 DOE, 4 NASA, 1 DOD) have been established through the NNI. The primary objective of the centers is to enable research activities that cannot be conducted through the traditional mode of single investigator, small groups, or with current research infrastructure. Further, each center is expected to establish partnerships with industry, national laboratories, and other sectors, including state supported nanoscience activities. The research activities of the centers are expected to enhance multidisciplinary research activities among government, universities and industry performers, which in turn, are expected to create a vertical integration arrangement that includes activities from basic research to the actual development of specific nanotechnology devices and applications.

4. The Creation of Research Infrastructure. *($108 million + $12 million)* The fourth theme supports the creation of a research infrastructure for metrology, instrumentation, modeling and simulation, and facilities. Most of the R&D instrumentation and facilities will be made available to users not only from the institution that operates the facility but also from other institutions including industry and government. The ultimate objective is the development of research instrumentation and facilities so that new innovations can be rapidly commercialized by U.S. industry. According to NSET, if the need for instrumentation and the ability to transition from knowledge-driven to product-driven efforts are not addressed satisfactorily, the United States will not remain internationally competitive in this field.

5. Ethical, Legal, and Social Implications. *($16million,+$3 million)* In concert with the initiative's university based research activities, this effort is designed to provide effective education and training of skilled workers in the multidisciplinary perspective necessary for rapid progress in nanotechnology. Researchers will also examine the potential social, economic, ethical, legal, and workforce implications of nanotechnology. In March of 2001, the NSET released a report on the Societal Implications of Nanoscience and Nanotechnology. Based on the proceedings of a two day workshop, the report states that support for research on the potential social, economic, and ethical implications must be a high priority for the NNI. According to the report, such efforts should help to reduce or dispel some of the unfounded fears that often accompany dramatic advances in science and engineering.[4]

Congressional Issues

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[4] For more details on this report, and other Federal nanotechnology related documents see, [http//www.nano.gov]

Coordination and Priority Setting for the NNI. In June of 2002, the National Research Council (NRC) released a report entitled *Small Wonders, Endless Frontier, A Review of the National Nanotechnolgy Initiative.* As part of its study the NRC was asked to examine such issues as the balance of the NNI R&D portfolio, the effectiveness of interagency coordination, and to identify important areas of future investments. As the first of ten major recommendations contained in the report, the NRC suggested that OSTP establish the National Nanotechnolgy Advisory Board (NNAB) which among other things could work with NSET agencies to reach beyond their individual research missions in order to identify "cross cutting research opportunities with the greatest potential payoff and the broadest impact."[5] The NRC panel was composed of representatives from industry, small business, and academia with scientific, engineering and social science backgrounds. The NRC report indicated that the NNAB could also address other NNI concerns, such as nano research infrastructure needs, technology transfer efforts, and the extent to which NSET R&D priorities reflect an awareness of private sector and international nanotechnology R&D activities. In response to the NRC recommendation, the President's Council of Advisors on Science and Technology (PCAST) has initiated a review of the NNI that will focus on three separate areas of inquiry. They include; 1.) medical, biological and social implications; 2.) materials and electronics; and 3.) energy and the environment. According to Dr. John Marberger, the Director of the Office of Science and Technology Policy, this initial PCAST study should be completed by late summer 2003, to aid with the development of NNI FY2005 budget priorities.

House and Senate NNI Legislation. Both the House (H.R. 766, Representatives Boehlert and Honda) and Senate (S. 189, Senators Wyden and Allen) have introduced legislation that would establish the NNI in law, noting that the major interagency initiative is a top priority for the Administration's FY2004 non-medical, civilian scientific and technology R&D. The House bill provides recommended authorization levels from FY2004-FY2006 for NSF, DOE, EPA, DOE, and NIST. The Senate bill contains recommended FY2004 authorization levels for all the civilian agencies participating in the NNI. The House and Senate bills contain provisions that would maintain multi-agency coordinating mechanisms, such as the NSET, as well the NNCO which is responsible for coordinating the daily activities of the NNI, and serving as a point of reference for responding to federal, state, and private sector inquiries related to the NNI. In response to the NRC report calling for an independent outside review of the NNI, the House and Senate bills call for the President to establish an independent advisory committee consisting of non-federal members, including representatives from academia and industry, as well as individuals who possess expertise regarding the ethical, legal, and social implications related to the development and deployment of nanotechnology. According to a House committee staffer, some Members of Congress are not convinced that PCAST possesses the time or the breadth of scientific and technological knowledge, related to nanotechnology, to conduct a comprehensive in-depth analysis of the NNI. Finally, both bills call for the National Academy Sciences to conduct periodic reviews of the NNI.

The Challenge of Interdisciplinary Research. In testimony before the Senate Commerce Subcommittee on Science, Technology and Space, R. Stanley Williams, from

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[5] *Small Wonders, Endless Frontiers, A Review of the National Nanotechnology Initiative,* National Research Council, National Academy Press, Washington D. C., 2002, p. 20.

Hewlett-Packard, testified that nanoscience is a field where hundreds of years of advancements in the fields of biology, physics, and chemistry have come together in just the past decade. According to Williams, now that all three fields have come together “each has realized that it can learn much from the others, so that the field of nanoscience has transcended traditional academic boundaries.”[6] Nevertheless, while the NRC report also recognizes the pivotal role that interdisciplinary scientific discovery will play in the advancement of nanoscience and nanotechnology, the report notes that most of the Nation’s education and research enterprise is not producing researchers who are capable of engaging in research that crosses disciplinary boundaries. In addition, the report notes that the overall academic value system regarding scientific quality “continues to discourage interdisciplinary research, with negative consequences for tenure, promotion, and the awarding of research grants.”[7] The 21st Century Nanotechnology Research and Development Act (S.189), contains a provision that would establish Interdisciplinary Research Centers, funded in the range of from $3-5 million per year, for the next 5 years. According to S. 189, the goal is to establish geographically diverse centers, including at least one center in a State participating in NSF’s Experimental Program to Stimulate Competitive Research (EPSCoR). Such centers could play a key role in developing a cadre of scientist and engineers trained in interdisciplinary studies to push the frontiers on nanoscience.

Nanotechnology Environmental and Health Concerns. Despite the great promise surrounding nanotechnology, questions have been raised regarding potential environmental and health concerns associated with the development and use of nanoscale materials. While nanotechnology may have the ability to make the environment cleaner, scientists acknowledge that manufacturing and use of nanomaterials could also present unique environmental concerns since these materials represent new types of matter. Dr. Mark Wisner, a researcher at the Center for Biological, and Environmental Nanotechnology (CBEN) at Rice University, has raised concerns about potential environmental effects when carbon nanotubes end up in the environment. As part of its NNI activities, the EPA is sponsoring research that will examine possible environmental concerns associated with the manufacturing and use of nano materials. Regarding health concerns, Dr. Vikki Colvin, a colleague of Dr. Wisner at CBEN, has reported that nanomaterials can insinuate themselves into cells which Colvin claims is unusual for most inorganic materials. She contends that we do not know what these new materials will do at the cellular level. While she believes that nanomaterials will interact with biology in ways that larger materials cannot, Dr. Wisner also noted that accumulation of materials in the liver of laboratory animals demonstrates that nanoparticles can accumulate within organisms. Wisner contends if we know nanomaterial can be taken up by cells, then there is an entry point for nanomaterial into the food chain. He suggested researchers should examine whether nanoparticles absorbed into bacteria enhance the ability to “piggyback“their way into the bacteria and cause damage to cellular structures.[8]

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[6] Stanley Williams, HP Fellow, Testimony before the Commerce Committee, Subcommittee on Science, Technology and Space, September 17, 2002., page 2.

[7] Op. Cit. *Small Wonders, Endless Frontiers*, p. 30.

[8] Smalltimes, *Nano Litterbugs? Expert See Potential Pollution Problems,* March/April, 2002