24

National Nanotechnology Investment in the FY 2006 Budget Request

M.C. Roco,[1]
Fellow, ASME International

The emerging fields of nanoscale science, engineering, and technology —the ability to work at the molecular level, atom by atom, to create large structures with fundamentally new properties and functions—are leading to unprecedented understanding and control over the basic building blocks and properties of all natural and man-made things. The FY 2006 budget for nanoscale science, engineering and technology (in brief, *nanotechnology*) research and development (R&D) in 11 federal departments and independent agencies is summarized in Table I-9. This investment is known as the National Nanotechnology Initiative (NNI).[2] Another 11 agencies and departments (listed in Table I-9) participate in kind and as partners. The vision of the NNI is a future in which the ability to understand and control matter on the nanoscale leads to a revolution in technology and industry. The four goals of the NNI are: 1/ Maintain a world-class research and development program aimed at realizing the full potential of nanotechnology; 2/Facilitate transfer of new technologies into products for economic growth, jobs, and other public benefit; 3/ Develop educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology; and 4/ Support responsible development of nanotechnology.

The supported R&D is grouped in seven program component areas (PCAs): (1) Fundamental nanoscale phenomena and processes; (2) Nanomaterials; (3) Nanoscale devices and systems; (4) Instrumentation research, metrology, and standards for nanotechnology; (5) Nanomanufacturing; (6) Major research facilities and instrumentation acquisition; and (7) Societal dimensions (including: environmental, health, and safety implications of nanotechnology development and risk

[1] Senior Advisor to the National Science Foundation, and Chair of NSTC's Subcommittee on Nanoscale Science, Engineering and Technology (NSET). The views expressed in this paper are not necessarily those of NSF or NSET.
[2] See the NNI's website http://nano.gov

assessment of such impacts; education; and research on the ethical, legal, and social implications of nanotechnology.)

Funding is provided on competitive basis with other programs and within NNI. In December 2004, President Bush signed into law the 21st Century Nanotechnology R&D Act (Public Law 108-153) with funding recommendations for five agencies (NSF, DOE, NASA, NIST and EPA) for fiscal years 2004-2008 and beyond. The National Science and Technology Council's (NSTC) Nanoscale Science, Engineering and Technology (NSET) Subcommittee coordinates the plans, budgets, programs, and reviews for NNI. NSET coordinates 22 federal departments and independent agencies in FY 2006, up from six at the beginning of the initiative in FY 2001. The President's Council of Advisors on Science and Technology (PCAST) was designated the National Nanotechnology Advisory Panel (NNAP) based on the Act. NSET published its long-term strategic plan in December 2004[3].

SUMMARY FOR ALL AGENCIES

Priorities in FY 2006: The FY 2006 request of $1.05 billion for NNI would be a 6.3 percent increase over the corresponding FY 2005 request of $988 million, but lower than FY 2005 appropriated amounts. One may note that the actual budget expenditures for nanotechnology have exceeded the President's requests every year since FY 2001. The FY 2006 increases would be at NSF, NIH, and USDA. The proposed cuts at DOD, DOE, and NASA may be explained by the reassignment of applied nanotechnology projects to the respective areas of relevance (DOD and NASA), by rescheduling several projects (DOE), and congressionally-directed funding in 2004 and 2005 (at DOD), as well as by the overall budget constraints in FY 2006. Roughly 65 percent of the funding proposed under the NNI supports academic research, about 25 percent to government R&D laboratories, and 10 percent to industry.

The initiative focuses on long-term research on understanding the manipulation of matter at the atomic and molecular levels, leading to an unprecedented ability to create nanostructured materials and systems for advanced products such as new classes of devices as small as molecules and machines as small as human cells. Applications areas include continued improvement in electronics for information technology; higher-performance, lower-maintenance materials and design for

[3] The NNI Strategic Plan, NSET, Washington, D.C., December 2004.

manufacturing, defense, transportation, space, and environment; accelerated, biotechnical applications in medicine, health care, and agriculture; and extending the limits of sustainable development. FY 2006 NNI priorities are: (1) advance the knowledge frontiers of nanoscale phenomena and processes to an extend that systematic control over matter at the nanoscale could be achieved; (2) research to enable design of hierarchically structured materials and efficient nanomanufacturing from the molecular scale; (3) increased research focus on active nanostructures and complex nanosystems; (4) nano-biosystems and medicine; (5) silicon nanoelectronics and beyond; (6) development of instrumentation, metrology and standards; (7) environmental, health and safety issues, including development of instrumentation for environmental and toxicity studies; (8) the education and training of the new generation or workers for the future industries; (9) addressing ethical and other social issues raised by the development of nanotechnology; (10) establish and operate major scientific user facilities with advanced instrumentation; and (11) partnerships to enhance industrial participation in the nanotechnology revolution. The priorities are under evaluation following NSET sponsored workshops[4].

***Collaborative activities*:** The NSTC NSET Subcommittee will coordinate joint activities that create synergies between the individual agencies in a variety of topics and modalities of collaboration. The coordination also will address NNI management issues, interaction with nanotechnology regional alliances, and international activities. The National Nanotechnology Coordinating office (NNCO) is the secretarial office of NSET for this purpose. Examples of specific coordination efforts are: nanomanufacturing (main partners NSF, DOD and NIST); environmental issues (EPA, NIOSH, NSF, and USDA); infrastructure development (such as among R&D centers, and centers and networks with DOE, DOD, NASA, NIH, and NIST); standards development (NIST, all other agencies); modeling and simulation and nanoelectronics (DOD, NASA and NSF); and interdisciplinary research at the intersection of nanotechnology, biotechnology, and information technology.

NATIONAL SCIENCE FOUNDATION (NSF)

The FY 2006 request is about $344 million, $6 million over the FY 2005 congressional appropriation (see Table 1).

[4] Details will be published in NNI Supplement to the President's FY 2006 Budget, Washington, D.C. (estimated to be released in April 2005).

Table 1. NSF Directorate Budgets for Nanoscale Science and Engineering **(in millions of dollars)**

NSF Directorate	FY 2004 Actual	FY 2005 Plan	FY 2006 Request
Biological Sciences	5.31	47.00	49.00
Computer and Information Science & Engineering	17.56	18.48	12.00
Engineering	108.88	127.77	127.77
Geosciences	7.94	7.94	9.00
Mathematical and Physical Sciences	111.48	132.14	141.54
Office of International Science and Engineering	0.00	0.26	0.00
Social, Behavioral and Economic Sciences	2.59	1.56	1.56
Subtotal, Research and Related Activities	253.76	335.15	340.87
Education and Human Resources	2.29	3.07	2.90
Total, Nanoscale Science and Engineering	$256.05	$338.22	$343.77

NSF supports fundamental knowledge creation across all disciplinary principles at the nanoscale.[5] Three new networks to be announced at the end of FY 2005 will establish their operation next year: the Center for Hierarchical Nanomanufacturing, the Center for Nanotechnology in Society, and the Center for Nanotechnology Informal Science Education. These networks, together with the existing ones (NNIN, NCN and Nanoscale Center for Learning and Teaching; see Table 2) will establish a research and education platform for nanotechnology at the national level, including open and remote access based on merit review, open access, and serve as clearinghouses for information. Research experience for undergraduates will be expanded at the Nanoscale Science and Engineering Centers.

NSF's planned investment for Nanoscale Science and Engineering in FY 2006 will contribute to all NNI program component areas. The largest contribution will be to "Fundamental nanoscale phenomena and processes" ($95 million). The investment on projects with primary

[5] The FY 2005 program solicitations can be found at http://www.nsf.gov/nano (Nanoscale Science and Engineering, NSF 03-043; and Nanoscale Science and Engineering Education, NSF 03-044) including exploratory, interdisciplinary teams and centers for research and education.

purpose focus on societal dimensions of nanotechnology is about $60 million. The education and training activities will be extended to undergraduate and K-12 education. The National Nanotechnology Infrastructure Network and the Network for Computational Nanotechnology will serve about 6,300 academic and industry users at their facilities (see Table 2 for key NNI R&D user facilities).

DEPARTMENT OF DEFENSE (DOD)

The FY 2006 request is $230 million, which is less than the FY 2005 request and the current plan (see Table I-10). The principal DOD participants in the NNI are the Directorate for Defense Research and Engineering (DDR&E), the Defense Advanced Research Projects Agency (DARPA), the Air Force, the Army and the Navy. DOD supports nanoscale science and technology in order to meet the national security mission. The DOD structures its S&T investment into basic research ("6.1"), applied research ("6.2") and advanced technology development ("6.3"); the latter two focus on transitioning science discovery into innovative technology.

Army, Navy and Air Force investment in "6.2" and "6.3" programs will grow in an effort to accelerate the transition of nanoscience research into mature nanotechnologies for use in military systems. Navy investment in "6.1" programs will be distributed though discovery and invention programs, and will vary based on the potential impact of nanotechnology within a given science and technology topical area.

New DARPA programs exploiting nanotechnologies are expected in 2006; specific topics have yet to be identified, but those under development will continue to emphasize the application of nanotechnology in applications important to national defense, such as quantum computation and nanoelectronic devices. There has been significant growth in congressionally directed funding for nanotechnology in the DOD budget. The historical progression has been approximately $80 million in 2003, approximately $103 million in 2004, and approximately $150 million in 2005. The Defense Threat Reduction Agency (DTRA) and the U.S. Army Medical Research and Materiel Command are evaluating nanotechnology as a possible investment area.

Nanoscience shows great promise for arrays of inexpensive, integrated, miniaturized sensors for chemical / biological / radiological / explosive

(CBRE) agents, for nanostructures enabling protection against agents, and for nanostructures that neutralize agents. The recent terrorist events motivate accelerated insertion of innovative technologies to improve the national security posture relative to CBRE. DOD will play a major role in this multiagency effort.[6]

DEPARTMENT OF ENERGY (DOE)

In FY 2006, the DOE NNI request is $207 million (see Table I-9). This is a slight decrease of $3 million from FY 2005. Fundamental research to understand the properties of materials at the nanoscale would be increased in three areas: synthesis and processing of materials at the nanoscale, condensed matter physics, and catalysis. In addition, the FY 2006 request includes a larger investment for all five centers (Nanoscale Science Research Centers, NSRC). All of the NSRCs are user facilities that are available to the entire R&D community, with time and staff support allocated on the basis of merit-reviewed proposals (see Table 2 for a list of the DOE and NSF centers). Throughout 2006, NSRC investment emphasis will transition from the construction and development phase to operations. The first NSRC, the Center for Nanophase Materials Science at the Oak Ridge National Laboratory, will commence full operations, and three other NSRCs will formally begin initial user operations as their dedicated buildings are completed.

Basic research on nanoscale phenomena and processes, and on nanomaterials, in support of the hydrogen economy will be increased. Funding levels for fundamental scientific research into nanoscale phenomena, nanomaterials, and other aspects of nanotechnology through grants to universities in 2006 request remain similar to those in 2005.

HHS: NATIONAL INSTITUTES OF HEALTH (NIH) AND NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH (NIOSH)

The NIH FY 2006 request is $144 million, up $2 million. NIH would receive nanoscience and nanotechnology grant applications under existing and renewed programs. These programs are managed individually by the Institutes and Centers, with peer review conducted for the most part by the NIH Center for Scientific Review. Overall

[6] The DOD nanotechnology budgets and programs are identified at http://nano.gov or http://www.nanosra.nrl.navy.mil.

nanotechnology program coordination occurs through the NIH Bioengineering Consortium (BECON).[7]

NIH's priority for nanotechnology research continues to be to create novel diagnostic and therapeutic approaches and devices, and new research capabilities to understand fundamental biomedical mechanisms, leading to improved health of the population and to reduce suffering from disease and disability.

Studies of biocompatibility are integral to many NIH-supported studies. For example, research to develop new nanotechnology-based imaging agents or restorative implants routinely include animal studies on the distribution, processing and excretion of these materials, and monitor for adverse effects that may occur during and after treatment. The NIH-wide Nanomedicine Roadmap, with planned initial funding of $6 million in 2005 would expand to $12 million in 2006. Programs of Excellence in Nanotechnology at the National Heart Lung and Blood Institute (NHLBI) would expand from a planned $6 million in 2005 to $12 million next year. And the National Cancer Institute's (NCI) NCI Alliance for Nanotechnology in Cancer would go from $32 million in 2005 to a request of $40 million in 2006.

The NIOSH FY 2006 request is $3 million, unchanged from the previous year. The Institute will finalize the establishment of a Center of Excellence for Nanotechnology Research, with the role of coordinating nanotechnology-related activities across the Institute and addressing critical occupational health issues. NIOSH will continue to develop partnerships with stakeholders and other organizations to enable the translation of agency activities into appropriate workplace practices.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA)

The FY 2006 NASA NNI request is approximately $32 million, $13 million below 2005 (see Table I-9). In addition to both Basic Nanoscience and Nanotechnology Research, NASA plans to invest in various application areas. The Basic NASA Nanoscience Program comprises Bio-Molecular Systems Research, which is a joint NASA/NCI Initiative. The OAT Program integrates nanotechnology development in

[7] The NIH nanoscience program announcements are available from www.nano.gov/nihnano.doc and http://grants.nih.gov/grants/becon/becon_funding.htm

three areas: (1) Materials and Structures, (2) Nanoelectronics and Computing, and (3) Sensors and Spacecraft Components. A major focus at NASA is to advance and exploit the zone of convergence between nanotechnology, biotechnology, and information technology. Areas to be emphasized include: ultrahigh strength and multi-functional materials; high density, low power electronics; ultra-small and sensitive sensors; and highly miniaturized spacecraft systems (from MEMS to NEMS, nanoelectromechanical systems). The NASA programs have been revised in the past year as result of the revised mission of the agency.

NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY (NIST)

The FY 2006 request is $75 million, unchanged from this year (see Table I-9). Projects in the following areas will be funded: molecular electronics; quantum computing; nanomagnetodynamics; nanotribology; and autonomous atom assembly. Approximately half of the total allocated funds will be used to continue current internal efforts in several of these areas and half will be used to leverage existing efforts with external partners. The funds are distributed, using a competitive process, across the NIST Laboratories for enabling infrastructural measurement, standards, and data for nanomagnetics, nanocharacterization, and new information technologies.

New nanomanufacturing and nanofabrication programs are inaugurated this year to support, at an enhanced level, research into nanoimprint lithography, particle metrology and other manufacturing metrology techniques. These programs also support development and delivery of measurement and infrastructural technologies to provide traceable metrology, process-control, and quality assurance for nanoscale manufacturing. Funding was also increased for research on measurements of nanomechanical properties and on nanotube/nanoparticle metrology, and for efforts to produce nanoelectronics and nanophotonics devices.

The National Nanomanufacturing and Nanometrology Facility (N^3F) opened in Gaithersburg, MD, in 2005. The N^3F was developed at NIST to support the development of new infrastructural metrology and standards for U.S. nanotechnology efforts through centralized access to NIST's unique nanometrology and nanofabrication resources, including the facilities of the Advanced Measurement Laboratory and NIST's nanometrology experts.

NIST plans to direct half of the new nanotechnology funding to these external organizations to conduct much of the specific work required to meet the goals of this initiative and avoid developing costly, complex in-house capabilities that may only be used once. NIST has a large range of collaborations with industry.

ENVIRONMENTAL PROTECTION AGENCY (EPA)

EPA's research is organized around the risk assessment/risk management paradigm. Research on human health and environmental effects, exposure, and risk assessment is combined to inform decisions on risk management. Research on environmental applications and implications of nanotechnology can be addressed within this framework. Nanotechnology may offer the promise of improved characterization of environmental problems, significantly reduced environmental impacts from "cleaner" manufacturing approaches, and reduced material and energy use. The potential impacts of nanoparticles from different applications on human health and the environment will be a focus area.

US DEPARTMENT OF AGRICULTURE (USDA)

The FY 2006 request is approximately $11 million, about $8 million over the FY 2005 current plan. USDA conducts its research both extramurally through the partnership between the Cooperative State Research, Education, and Extension Service (CSREES), the Land Grant Universities (LGUs), and in-house at Agriculture Research Service (ARS) laboratories. CSREES also provides leadership and financial supports in education and outreach in all the states and territories of the U.S. through the LGUs. The USDA nanotechnology program will further expand in 2006 through its Nanotechnology Research Initiative for extramural competitive research and education grants. R&D efforts will contribute to the NNI program component areas, with a central theme of exploiting the novel properties of nanoscale biological structures derived from important agricultural materials. The development of nanotechnology-based sensors for application in the food industry and agriculture is also a priority, and will similarly expand.

DEPARTMENT OF HOMELAND SECURITY (DHS)

The FY 2006 research request remains unchanged, at approximately $1

million, for the Transportation Security Administration (TSA) to address one of the agency's most critical missions today: ensuring the security of our nation's air transportation system by improving the detection of explosives and chemical/biological weapons. R&D programs aim to detect explosives and hazardous chemicals at the nanometer level and to characterize the interactions of explosives on material surfaces at this scale. Further research will yield sensor technologies that are cheaper and lighter yet far more sensitive, selective, and reliable than current systems.

DEPARTMENT OF JUSTICE (DOJ)

In FY 2006 the budget request is steady at $2 million. The DOJ National Institute of Justice (NIJ) has two separate projects areas that incorporate nanotechnology—DNA Research ($1.0 million) and Development and Chemical and Biological Defense ($1 million). The DNA Research and Development program will continue basic research as well as the demonstration of chip-based or micro-device technologies to analyze DNA in forensic applications. The Chemical and Biological Defense program is developing a wearable, low-cost device to provide warning of exposure to unanticipated chemical and biological hazards in sufficient time for its wearer to take effective protective measures. Evolving nanotechnology may be used to address limitations of the current enzymatic approach.

Table 2. Key NNI R&D user facilities

Center Name	**Institution**
NSF	
National Nanofabrication Infrastructure Network (NNIN) – 13 nodes	Cornell University –central node
Network for Computational Nanotechnology (NCN) – 7 nodes	Purdue University – central node
DOE	
Center for Functional Nanomaterials	Brookhaven National Laboratory
Center for Integrated Nanotechnologies	Sandia NL and Los Almos NL
Center for Nanophase Materials Sciences	Oak Ridge National Laboratory
Center for Nanoscale Materials	Argonne National Laboratory
Molecular Foundry	Lawrence Berkeley National Laboratory