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National Nanotechnology Investment in the FY 2005 Budget Request

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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 2005 request for nanoscale science, engineering and technology (in brief, **nanotechnology**) research and development (R&D) in ten federal departments and independent agencies is summarized in Table I-10. This investment is known as the National Nanotechnology Initiative (NNI).[2] NNI emphasizes long-term, fundamental research aimed at discovering novel phenomena, processes, and tools; addressing "Grand Challenges" for key areas of application; supporting new interdisciplinary centers and networks of excellence including shared user facilities; supporting research infrastructure; and addressing research and educational activities on the societal implications of advances in nanoscience and nanotechnology. Congress approved in November 2003 and the President signed in December 2003 the "21st Century Nanotechnology R&D Act" with funding recommendations for fiscal years 2004-2008 and beyond.

SUMMARY FOR ALL AGENCIES

Priorities in FY 2005: The FY 2005 President's request of $982 million for federal investment in nanoscale science, engineering and technology, is a 2 percent increase over the FY 2004 appropriation of $961 million (Table I-10). The FY 2005 budget increases are at the National Science Foundation (NSF), the Department of Energy (DOE), the National

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[2] See the NNI's website http://nano.gov

Institutes of Health (NIH) and the U.S. Department of Agriculture (USDA). The budget decreases in the same request at the Department of Defense (DOD), the National Aeronautics and Space Administration (NASA) and the National Institute of Standards and Technology (NIST) may be explained by the reassignment of applied nanotechnology projects to the respective areas of relevance (at DOD and NASA) and by rescheduling several projects (at NIST). Roughly 65 percent of the funding proposed under the NNI supports academic research.

The initiative focuses on long-term research on the manipulation of matter at the atomic and molecular levels, giving us an unprecedented ability to create building blocks for advanced products, such as new classes of devices as small as molecules and machines as small as human cells. This research could lead to continued improvement in electronics for information technology; higher-performance, lower-maintenance materials for manufacturing, defense, transportation, space, and environmental applications; accelerated, biotechnical applications in medicine, health care, and agriculture; and extending the limits of sustainable development. In FY 2005, priority in R&D funding will be given to: (1) research to uncover new phenomena and properties of materials at the nanoscale; (2) research to enable the nanoscale as the most efficient manufacturing domain; (3) innovative nanotechnology solutions to biological-chemical-radiological-explosive detection and protection; (4) nano-biosystems and medicine; (5) nanoelectronics beyond CMOS; (6) development of instrumentation and standards; (7) environmental and health issues; (8) the education and training of a new generation of workers for future industries; and (9) partnerships to enhance industrial participation in the nanotechnology revolution. The convergence of nanotechnology with information technology, modern biology and social sciences will reinvigorate discoveries and innovation in almost all areas of the economy. Areas of growth are nanotechnology research for nanoscale systems and their manufacturing, energy conversion, and agriculture and food systems. Long-term NNI priorities are under evaluation following a series of NSET sponsored workshops.[3]

***Collaborative activities*:** The National Science and Technology Council (NSTC) Subcommittee on Nanoscale Science, Engineering and Technology (NSET) will coordinate joint activities that create synergies

[3] Details will be published in "NNI – R&D Supporting the Next Industrial Revolution", *Supplemental Report to the President's FY 2005 Budget,* Washington, D.C. (estimated to be released in June 2004).

between the individual agencies in a variety of topics and modalities of collaboration. The coordination will identify the most promising research directions; fund complementary/synergistic fields of research that are critical for the advancement of the nanoscience and engineering field; develop a balanced infrastructure (portfolio of programs, development of new specific tools, instrumentation, simulation infrastructure, standards for nanoscale); correlate funding activities for centers and networks of excellence; cost-share high-cost R&D activities; develop a broad workforce trained in the many aspects necessary to nanotechnology; study the diverse, complex implications for society; and avoid unnecessary duplication of efforts. 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.

NATIONAL SCIENCE FOUNDATION (NSF)

The FY 2005 request is about $305 million, a $56 million increase over the FY 2004 request and $51 million over FY 2004 (see Table 1).

The Nanoscale Science and Engineering (NSE) Group coordinates NNI activities. Each directorate has two representatives in the NSE Group. The Chair of the Group is the NSF representative in NSET, and its current chair.[4] The NSF investment will be expanded to develop and strengthen critical fields and to establish the science and engineering infrastructure and workforce needed to exploit the opportunities presented by new capabilities. Support will be focused on interdisciplinary research and education teams, national science and engineering centers, exploratory research and education projects, and education for high schools and public outreach.

The investment will expand a wide range of research and education activities in this priority area, including approximately 20 nanotechnology research and education centers focusing on electronics, biology, optoelectronics, advanced materials and engineering (see Table 2).

[4] The FY 2004 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.

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

NSF Directorate	FY 2003 Plan	FY 2004 Plan	FY 2005 Request
Biological Sciences	2.98	5.31	5.85
Computer and Information Science & Engineering	11.14	15.79	19.40
Engineering	94.35	108.88	133.81
Geosciences	7.53	7.94	7.88
Mathematical and Physical Sciences	103.92	111.48	132.14
Office of International Science and Engineering	n/a	n/a	0.26
Social, Behavioral and Economic Sciences	1.11	1.56	1.50
Subtotal, Research and Related Activities	221.03	250.96	300.84
Education and Human Resources	0.22	2.55	4.16
Total, Nanoscale Science and Engineering	$221.25	$253.51	$305.00

Long-term objectives include laying a foundation of fundamental research for NNI Grand Challenges; ensuring that U.S. institutions will have access to a full range of nano-facilities; enabling access to nanotechnology education for students in U.S. colleges and universities; and catalyzing the creation of new commercial markets that depend on three-dimensional nanostructures. This should result in the development of completely new technologies that contribute to improvements in health, advanced agriculture, conservation of materials and energy, and sustainability of the environment. This investment will be expanded in FY 2005 to develop and strengthen critical fields and to establish the science and engineering infrastructure and workforce needed to exploit the opportunities presented by these new capabilities, including nanoelectronics and nanobiotechnology. Converging technologies from the nanoscale, with a focus on improving human performance, will be included. In addition to single-investigator research, support will be focused on interdisciplinary research and education teams, national science and engineering centers, exploratory research and education projects, and education and training.

NSF's planned investment for Nanoscale Science and Engineering in FY 2005 will have five programmatic foci: 1) Fundamental Research and Education, $174 million; 2) Grand Challenges, approximately $11.9 million; 3) Centers and Networks of Excellence, approximately $57.5

million (see Table 2 for a list); 4) Research Infrastructure, approximately $36.9 million; and 5) Societal and Educational Implications of Science and Technology Advances, approximately $24.7 million. The education and training activities will be extended to undergraduate and K-12 education. The National Nanotechnology Infrastructure Network will be expanded in its second year in FY 2005, to about $15 million, and the Network for Computational Nanotechnology to about $3 million.

DEPARTMENT OF DEFENSE (DOD)

The FY 2005 request is $276 million, $39 million less than planned in FY 2004 (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.

The University Research Initiative program in FY 2001 added 16 nanoscience projects as part of a Defense University Research Initiative on Nanotechnology (DURINT) competition and another five nanoscience projects under the traditional competition; the projects carry a five-year commitment in FY 2005. DARPA would have a significant contribution in the nanoscience/nanotechnology investment portfolio in FY 2004. The Air Force is looking to increase its investment in nanoscience. It is anticipated that its basic research activities will expand research in nanocomposites and hybrid polymer-inorganic nanocomposites; self-assembly and nanoscale processing for the realization of 3-D optical and electronic circuitry; highly efficient space solar cells; nanoenergetics (understanding the factors that control reactivity and energy release in nanostructured systems); nanostructures for highly selective sensors and catalysts; as well as nanoelectronics, nanomagnetics and nanophotonics, nanostructured coatings, ceramics and metals. The Army has allocated $10 million of basic research funds for the Institute for Soldier Nanotechnologies at the Massachusetts Institute of Technology (MIT; see Table 2). The purpose of this center of excellence is to develop unclassified nanometer-scale science and technology solutions for the soldier. A single university will host this center, which will emphasize revolutionary materials research toward

advanced soldier protection and survivability capabilities. The Naval Research Laboratory has initiated a Nanoscience Institute to enhance multidisciplinary thinking and critical infrastructure.

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.[5]

DEPARTMENT OF ENERGY (DOE)

In FY 2005, the total request is $211 million, an increase of $8 million over FY 2004 (see Table I-10). 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 2005 request includes a larger investment for all five centers (Nanoscale Science Research Centers, NSRC; see Table 3). NSRCs are user facilities for the synthesis, processing, fabrication, and analysis of materials at the nanoscale. NSRCs were conceived within the context of the NSTC Interagency Working Group on Nanoscale Science, Engineering, and Technology as part of the DOE contribution to NNI. They involve conventional construction of a simple laboratory building, usually sited adjacent to or near an existing DOE Basic Energy Sciences (BES) synchrotron or neutron scattering facility. The research activity will also benefit by the work proposed in FY 2005 by the Office of Advanced Scientific Computing Research to develop specialized computational tools for nanoscale science.

NATIONAL INSTITUTES OF HEALTH (NIH)

The FY 2005 request is $89 million, $9 million over the FY 2004 appropriation. 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 nanotechnology program coordination occurs through the NIH

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

Bioengineering Consortium (BECON).[6] NIH plans to increase its focus on biological and medical applications of nanotechnology.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA)

The FY 2005 NASA NNI request is approximately $35 million, $2 million less than this year (see Table I-10). In addition to the $22 million in both Basic Nanoscience and Nanotechnology Research, NASA plans to invest approximately an additional $9 million in the area of Nanotechnology Science and Applications. These investments are embedded within several program areas within the Office of Biological and Physical Research and the Office of Aerospace Technology (OAT). The Basic NASA Nanoscience Program comprises Bio-Molecular Systems Research, which is a joint NASA/NCI (National Cancer Institute) Initiative, and the second is in Biotechnology and Structural Biology. The OAT Program integrates Nanotechnology development in 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.

Collaboration is particularly important for NASA, since it recognizes the importance of importing technologies from other federal agencies, particularly NSF, DOD, the National Institutes of Health (NIH), and the Department of Energy (DOE). NASA will focus primarily on NASA-unique needs; examples are low power devices and high strength materials that perform with exceptional autonomy in the hostile space environment. NASA has increased university participation in nanotechnology programs by competitively awarding four University Research, Engineering and Technology Institutes (RETIs) in FY 2003 (see Table 2). Each award is about $3 million a year for five years with the option to extend for up to an additional five years.

NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY (NIST)

The FY 2005 request is $53 million, down $10 million (see Table I-10). Projects in the following areas will be funded: molecular electronics; quantum computing; nanomagnetodynamics; nanotribology; and

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

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. Areas of focus are: (a) Nanomagnetics research for measurement and standards for current and near-term applications of nanotechnology in the semiconductor, communications, and health care industries; (b) Nanocharacterization research to produce standards and tools for visualization and characterization at the nanoscale, which are in high demand by a broad base of U.S. industries; (c) Research to provide fundamental measurements needed for future generations of information technology hardware that will be needed to replace semiconductor electronics technology in about a decade. In order to leverage internal efforts, NIST will develop stronger strategic alliances and collaborations with universities, businesses, and other government agencies that possess leading expertise in nanotechnology. 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.

ENVIRONMENTAL PROTECTION AGENCY (EPA)

FY 2005 research is expected to be similar to FY 2004 at approximately $5 million. 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.

U.S. DEPARTMENT OF AGRICULTURE (USDA)

The FY 2005 request is approximately $5 million, about five times larger than FY 2004. USDA conducts its research both extramurally through

the partnership between the Cooperative State Research, Education, and Extension Service (CSREES) and 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 states and territories of the U.S. through the LGUs.

DEPARTMENT OF HOMELAND SECURITY (DHS)

The FY 2005 request is $2 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. The NNI activities proposed for FY 2005 will build on current efforts to expedite the fielding of far more accurate and effective security technology at our nation's airports.

DEPARTMENT OF JUSTICE (DOJ)

In FY 2005 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. Nanotechnology has or will be a significant part of the device under development that will eventually be integrated into the current crime laboratory processes and protocols to analyze forensic DNA samples. 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. The current approach relies on an enzymatic reaction. It is based on vapor exposure of an immobilized enzyme surface. Evolving nanotechnology may be used to address limitations of the enzymatic approach.

Table 2. NNI centers and networks of excellence

Center Name	Institution
NSF	
Nanoscale Systems in Information Technologies, NSEC (Nanoscale Science and Engineering Center)	Cornell University
Nanoscience in Biological and Environmental Engineering	Rice University
Integrated Nanopatterning and Detection, NSEC	Northwestern University
Electronic Transport in Molecular Nanostructures, NSEC	Columbia University
Nanoscale Systems and their Device Applications, NSEC	Harvard University
Directed Assembly of Nanostructures, NSEC	Rensselaer Polytechnic Institute
Nanobiotechnology, Science and Technology Center	Cornell University
NSEC	UCLA
NSEC	UIUC
ERC	U. Colorado, Boulder
DOD	
Institute for Soldier Nanotechnologies	MIT
Center for Nanoscience Innovation for Defense	UC Santa Barbara
Nanoscience Institute	Naval Research Laboratory
NASA	
Institute for Cell Mimetic Space Exploration	UCLA
Institute for Intelligent Bio-Nanomaterials & Structures for Aerospace Vehicles	Texas A&M
Bio-Inspection, Design and Processing of Multi-functional Nanocomposites	Princeton
Institute for Nanoelectronics and Computing	Purdue

Table 3. NNI R&D user facilities

Center Name	Institution
NSF	
National Nanofabrication Infrastructure Network (NNIN) – 13 nodes	Cornell University –central node
Network for Computational Nanotechnology	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