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The National Nanotechnology Initiative

BRIEF HISTORY

Attempts to coordinate federal work on the nanoscale began in November 1996, when staff members from several agencies decided to meet regularly to discuss their plans and programs in nanoscale science and technology. This group continued informally until September 1998, when it was designated as the Interagency Working Group on Nanotechnology (IWGN) under the National Science and Technology Council (NSTC) of the OSTP.[1]

The IWGN laid the groundwork for the National Nanotechnology Initiative (NNI). It sponsored numerous workshops and studies to define the state of the art in nanoscale science and technology and to forecast possible future developments. Two relevant background publications were produced by the group between July and September 1999: *Nanostructure Science and Technology: A Worldwide Study*,[2] a report based on the findings of an expert panel that visited nanoscale science and technology laboratories around the world; and *Nanotechnology Research Directions,*[3] a workshop report with input from academic, private sector, and government participants. These documents laid the groundwork and provided the justification for seeking to raise nanoscale science and technology to the level of a national initiative. In August 1999, IGWN completed its first draft of a plan for an initiative in nanoscale science and technology. The plan went through an approval process involving the President's Council of Advisors on Science and Technology (PCAST)[4] and OSTP; subsequently, in its 2001 budget submission to Congress, the Clinton administration raised nanoscale science and technology to the level of a federal initiative, officially referring to it as the National Nanotechnology Initiative.

ADMINISTRATION OF THE INITIATIVE

Once the NNI had been set up, the IWGN was disbanded and Nanoscale Science, Engineering and Technology (NSET) was established as a subcommittee of the National Science and Technology Council's (NSTC) Committee on Technology (CT). CT, which is composed of senior-level representatives from the federal government's research and development departments and agencies, provides policy leadership and budget guidance for this and other multiagency technology programs.

NSET is responsible for coordinating the federal government's nanoscale research and development programs. NSET membership includes representatives of departments and agencies currently involved in the NNI and OSTP officials. The National Nanotechnology Coordination Office (NNCO) was established to serve as the secretariat for NSET, providing day-to-day technical and administrative support. The NNCO supports

[1]M.C. Roco, National Science Foundation, presentation to the committee, August 16, 2001.

[2]*Nanostructure Science and Technology: A Worldwide Study,* R.W. Siegel, E. Hu, and M.C. Roco, eds. Kluwer Academic Publishers, 1999. Available at <http://itri.loyola.edu/nano/final/>.

[3]*Nanotechnology Research Directions, IWGN Workshop Report, Vision for Nanotechnology Research in the Next Decade,* M.C. Roco, S. Williams, and P. Alivisatos, eds. Kluwer Academic Publishers, 2000.

[4]PCAST consists of nongovernmental experts who provide advice to the President on science and technology issues.

TABLE 2.1 Estimated Funding for Nanotechnology from FY 1999 to FY 2003 (million dollars)

Organization[a]	FY 1999	FY 2000	FY 2001	FY 2002 Estimate	FY 2003 Request
NSF	85	97	150	199	221
DOD	70	70	123	180	201
DOE	58	58	88	91	139
DOJ			1	1.4	1.4
DOT				2	2
NIH[b]	21	32	40	41	43
NASA	5	5	22	46	51
NIST[c]	16	8	33	38	44
EPA			5	5	5
USDA			2	1.5	2.5
Total	255	270	464	604.9	709.9

[a]Funding figures for four additional entities (the Departments of State and Treasury, the CIA, and the Nuclear Regulatory Commission) that are also joining the NNI are not yet available.
[b]In the Department of Health and Human Services.
[c]In the Department of Commerce.

NSET in multiagency planning and the preparation of budgets and program assessment documents. It also assists NSET with the collection and dissemination of information on industry, state, and international nanoscale science and technology research, development, and commercialization activities. Currently represented on NSET are the Departments of Defense (DOD), Energy (DOE), Justice (DOJ), Transportation (DOT), Agriculture (USDA), State, and Treasury; the Environmental Protection Agency (EPA); the National Aeronautics and Space Administration (NASA); the National Institutes of Health (NIH); the National Institute of Standards and Technology (NIST); the National Science Foundation (NSF); the Nuclear Regulatory Commission (USNRC); the Central Intelligence Agency (CIA); and two White House offices (the Office of Management and Budget (OMB) and OSTP).

According to the NNI implementation plan,[5] each agency invests in projects that support its own mission and retains control over how it will allocate resources against its NNI proposals based on the availability of funding. Each agency evaluates its own research activities within the NNI according to its own Government Performance and Results Act (GPRA) procedures. NNI coordination should result from NSET activities, direct interactions among program officers from the participating agencies, periodic management meetings and program reviews, and joint scientific and engineering workshops. OSTP works with the NSET and with individual agencies to establish NNI priorities, budgets, and metrics for evaluating various research activities.

STATUS OF FUNDING

The NNI has received strong Presidential and congressional support. Table 2.1 presents funding for nanoscale science and technology from 1999 to the present. For the purposes of determining which programs are to be included in the tally of federal "nanotechnology" funding, the OMB has developed a definition of nanotechnology to guide federal agencies in the reporting of their respective research efforts.[6] While

[5]*NNI: Leading to the Next Industrial Revolution. The Initiative and Its Implementation Plan*, NSTC, July 2000, pp. 38-40.

[6]Contained in Circular A-11, 1465-xx, NNI research activities are defined as follows:

> . . . research and technology development at the atomic, molecular, or macromolecular levels, in the length scale of approximately 1-100 nanometer range, to provide a fundamental understanding of phenomena and materials properties at the nanoscale and to model, create, characterize, manipulate, and use structures, devices, and systems that have novel properties and functions because of their small or intermediate size. The novel and differentiating properties and function are developed at a critical length scale of matter typically under 100 nanometers. Nanotechnology research and development includes integration of nanoscale structure into larger material components, systems, and architectures. Within these larger scale assemblies, the control and construction of their structures and components devices remain at the nanometer scale.

the Bush administration's FY 2002 budget included a request for $485 million for the NNI, almost a 15 percent increase over FY 2001, Congress approved an estimated $604.9 million, a 30 percent increase over FY 2001 (see Table 2.1). However, according to some NSET representatives, 25 to 30 percent of the $140 million increase can be attributed to the reclassification or reallocation of existing agency research expenditures into the NNI program. Three agencies, NSF, DOD, and NASA, accounted for the majority of additional federal expenditures for the NNI in FY 2002. Since FY 1999, federal support for the NNI has received average annual increases of 33 percent.

The FY 2002 Department of Veterans Affairs subcommittee appropriations bill (which contains annual appropriations for the NSF, NASA, EPA, and other federal agencies) noted the Senate Appropriations Committee's strong support for "the interagency nanoscience and technology initiative." The report's language requests that OSTP and the NSET update the FY 2001 NNI Implementation Plan as a supplemental report to the President's FY 2003 budget request. The Appropriations Committee specifically requested that the report include a detailed discussion on "agency efforts to transfer nanotechnology research efforts into applications."[7] It requested an update of the NNI implementation plan because the plan had not been significantly revised since 1999. Further, the Appropriations Committee wanted to know if OSTP and NSET representatives are working together to establish mechanisms that will enhance the transfer of NNI research results from the laboratory into commercial applications.

The NNI implementation plan, as currently drafted, incorporates a series of primary themes that are described in this report and highlights a number of Grand Challenges facing the successful development and deployment of nanoscale science and technology in general and the NNI in particular. The existing Grand Challenges (11 in number in the FY 2001 NNI summary) are meant to spur the development required to meet the goal of economic growth through nanotechnology and to form a basis for examining program support for specific initiatives.

For FY 2003, the Bush administration has designated the NNI as a multiagency research initiative that will benefit from improved coordination across multiple agencies. As indicated in Table 2.1 and mentioned previously, the administration has proposed $709.9 million for the NNI, a 17 percent increase over the FY 2002 estimated level of $604.9 million. Three agencies—DOE, DOD, and NSF—account for over 90 percent of the proposed FY 2003 increase. However, according to NSET officials, the NSF and the NIH are the only agencies whose FY 2003 increases included new funding.

For FY 2003 the initiative will continue to focus on fundamental nanoscale science and technology research, centers and networks of excellence, and support of new research infrastructure. The NSET has approved the creation of a twelfth Grand Challenge, which will focus on homeland defense: Chemical, Biological, Radiological, and Explosive (CBRE) Detection and Protection.

BRIEF DESCRIPTION OF THE INITIATIVE

The NNI is built around five funding themes distributed among the agencies currently funding nanoscale science and technology research.[8] These themes are described below, with estimated FY 2002 funding and requested increases for FY 2003. Table 2.2 details the distribution of funds between these five themes for FY 2001.

• *Long-term fundamental nanoscience and engineering research ($201 million, +$31 million).* Long-term basic nanoscience and engineering research will focus on fundamental understanding and synthesis of nanometer-size building blocks aimed at potential breakthroughs in areas such as materials and manufacturing, nanoelectronics, medicine and health care, environment and energy, the chemical and pharmaceuticals industries, biotechnology and agriculture, computation and information technology, and national security. This investment is intended to provide sustained support for individual investigators and small groups doing fundamental research, to promote university-industry-federal laboratory partnerships, and to foster interagency collaboration.

• *Grand Challenges ($180 million, +$24 million).* The second theme includes support for interdisciplinary research and education teams, including centers and networks, that work on key long-term objectives.

[7]Departments of Veterans Affairs and Housing and Urban Development, and Independent Agencies Appropriations Bill, 2002. S. 1216, Senate Report 107-43, page 89.

[8]*NNI: Leading to the Next Industrial Revolution: The Initiative and Its Implementation Plan,* NSTC, July 2000.

TABLE 2.2 Distribution of Funds Between the Five NNI Funding Themes for FY 2001, the First Year of the Initiative (million dollars)

Agency	Fundamental Research	Grand Challenges	Centers and Networks of Excellence	Research Infrastructure	Societal Implications	Agency Total
NSF	84	8	26	17	15	150
DOD	20	58	24	21	0	123
DOE	25	34	14	15	0	88
NIH	9	19	1	9	2	40
NASA	4	11	2	5	0	22
NIST	0	16	9	8	0	33
EPA	0	2	2	1	0	5
DOJ	0	1	0	0	0	1
DOT	0	0	0	0	0	0
USDA	2	0	0	0	0	2
Total	144	149	78	76	17	464

NOTE: FY 2002 funding data were incomplete at the time of this report's publication.

The Bush administration has identified a dozen Grand Challenges that are essential for the advancement of nanoscale science and technology. They include the design and manufacture of nanostructured materials that are correct at the atomic and single-molecule level. These advances are aimed at applications such as cost-effective manufacture of nanoscale microelectronics, more efficient and cost-effective energy conservation and storage devices, and biological sensors with applications to both health care and chemical and biological threat detection. Many of the Grand Challenges are aligned with the mission of the various agencies participating in the NNI.

• *Centers and networks of excellence ($96 million, +$23 million).* The third theme is the establishment of 10 centers and networks of excellence, each of which would be funded at about $3 million a year for 5 years. Pending a successful interim progress review, each center could receive a one-time 5-year renewal. The centers will play a key role in achieving top NNI priorities (fundamental research, grand challenges, educating future scientists and engineers), in developing and utilizing specific nanoscale research tools, and in promoting research partnerships. The administration anticipates that the establishment of centers and networks will spawn the integration of research and education in nanoscale science and technology across disciplines and by various research sectors, including universities, federal laboratories, and the private sector. It anticipates that interdisciplinary research activities by government, university, and industrial performers will create a vertical integration arrangement that includes activities from basic research to the development of specific nanotechnology devices and applications.

• *Research infrastructure ($97 million, +$23 million).* The fourth theme supports the creation of a research infrastructure for metrology, instrumentation, modeling and simulation, and facilities. To work at the nanoscale, new research tools—for example, new forms of lithography, computational capabilities, and instruments for manipulation—will have to be developed. New research centers possessing such instrumentation will be built and made available to researchers from universities, industry, and government laboratories. The ultimate objective is new innovations that can be rapidly commercialized by U.S. industry. According to NSET representatives, if the need for instrumentation and the ability to make the transition from knowledge-driven to product-driven efforts are not addressed satisfactorily, the United States will not remain internationally competitive in this field.

• *Ethical, legal, and social implications and workforce education and training ($30 million, +$5 million).* The societal implications of nanotechnology and workforce education and training constitute the fifth theme of the NNI. In concert with the initiative's university-based research activities, this effort is designed to educate and train skilled workers, giving them the interdisciplinary perspective necessary for rapid progress in nanoscale science and technology. Researchers will also examine the potential ethical,

legal, social, and workforce implications of nanoscale science and technology.

As part of the FY 2002 budget submission, key outcomes expected from the NNI in fiscal years 2002-2006 were outlined; these are given in Table 2.3. However, because Congress did not pass most of its FY 2002 appropriations bills until December 2001, the agencies involved in the NNI are not yet in a position to assess their FY 2002 activities for this report.

The NSET, working with the National Nanotechnology Coordination Office (NNCO), has tried to identify the most promising complementary and synergistic fields of research being carried out by the various NNI agencies in order to develop collaborations that will advance nanoscience and engineering. According to NNI documents, an important goal of these multi-agency collaborative efforts is to coordinate funding activities for centers and networks of excellence, to share the costs of expensive research initiatives, and to study potential societal implications surrounding the adoption of nano-related capabilities, while reducing the probability of duplicative research efforts. Table 2.4 provides an overview of major collaborations planned by the NNI member agencies, as listed in the NNI implementation plan.

TABLE 2.3 Key Outcomes Planned for NNI from FY 2002 to 2006

Outcome	Target Date
Provide augmented research and development in fundamental research, grand challenges, infrastructure, education, and nanotechnology societal impacts in response to open competitive solicitations and regular program reviews.	FY 2002
Increase work on teams and centers for pursuing agency mission objectives.	FY 2002
Establish 10 new centers and networks with full range of nanoscale measurement and fabrication facilities.	FY 2002
Establish three distributed consortia for nanotechnology research and applications in transportation.	FY 2002
Begin focused research on nanoscale experimental tools and manufacturing at the nanoscale.	FY 2002
Develop new standard reference materials for semiconductor nanostructures, lab-on-a-chip technologies, nanomagnetics, and calibration and quality assurance analysis for nanosystems.	FY 2003
Leverage NNI funds by 25% by working with states, universities, and the private sector to increase funding and synergism in R&D, to nucleate new clusters of industries.	FY 2003
Develop standardized, reproducible, microfabricated approaches to nanocharacterization, nanomanipulation, and nanodevices.	FY 2004
Develop quantitative measurement methods for nanodevices, nanomanipulation, nanocharacterization, and nanomagnetics.	FY 2004
Develop 3D measurement methods for the analysis of physical and chemical properties at or near atomic spatial resolution.	FY 2004
Ensure that 50% of research institutions' faculty and students have access to full range of nanoscale research facilities.	FY 2005
Enable access to nanoscience and engineering education for students in at least 25% of research universities.	FY 2005
Catalyze creation of several new commercial markets that depend on 3D nanostructures.	FY 2005
Develop 3D modeling of nanostructures with increased speed and accuracy to allow practical system and architecture design.	FY 2005
Nanoelectronics: first terabit memory chip demonstrated in the laboratory.	FY 2006
Introduce manufacturing at nanoscale for three new technologies.	FY 2006
Monitor contaminants in air, water, and soils with increased accuracy for better environmental quality and reduced emissions.	FY 2006
Integrate facilities for nanoscale and microscale testing and manufacturing at 10 R&D centers.	FY 2006
Develop methods, tools, and computational tools for structure analysis for the extraction of information from nature's nanoscale materials and machines.	After 2006
Incorporate biological molecules into otherwise electronic devices, mimic biological structures in fabricated devices, and incorporate lessons learned from biological signal processing into the logic of electronic systems.	After 2006
Conduct nanoscale measurements on microsecond time scales to provide a blueprint for the development of nanomachines and synthetic molecular processors that carry out complex functions.	After 2006
Use photovoltaic proteins in plants that extract electronic energy from light energy, or insect hearing organs 1 mm apart that have highly directional sound source localization sensitivity, as models for, or components of, nanosystems that accomplish other functions.	After 2006

NOTE: NNI implementation plan, FY 2002 update, January 15, 2001, draft, pp. 13-14. The plan states as follows: "Out-year deliverables depend on regular increases in funding for this initiative."

TABLE 2.4 Examples of Major Collaborations Planned by NNI Participating Agencies

Area of Investment	DOD	DOE	DOJ	DOT	Treasury	EPA	NASA	NIH	NIST	NSF	USDA
Fundamental research	X	X		X	X		X	X		X	
Nanostructured materials	X	X		X	X	X	X	X	X	X	X
Molecular electronics	X						X		X	X	
Spin electronics	X						X			X	
Lab-on-a-chip	X	X	X	X	X		X	X	X	X	X
Biosensors, bioinformatics			X				X	X		X	
Bioengineering	X	X						X		X	
Quantum computing	X	X					X		X	X	
Measurements and standards for tools	X	X		X		X		X	X	X	X
Nanoscale theory, modeling, simulation	X	X					X			X	X
Environmental modeling		X				X	X			X	
Nanorobotics		X					X			X	
Unmanned missions	X						X				
International collaborations	X	X	X	X	X	X	X	X	X	X	X
Nanofabrication user facilities		X		X		X	X	X	X	X	X