NANOSCALE SCIENCE AND ENGINEERING

Nanoscale Science and Engineering (NS&E) is the NSF priority area contributing to the multiagency National Nanotechnology Initiative (NNI). NS&E at NSF encompasses the systematic understanding, organization, manipulation and control of matter at the atomic, molecular and supramolecular levels. Novel materials, devices, and systems – with their building blocks on the scale of nanometers – open up new directions in science, engineering and technology with potentially profound implications for society. With the capacity to manipulate matter at this scale, science, engineering and technology are realizing revolutionary advances, in areas such as individualized pharmaceuticals, new drug delivery systems, more resilient materials and fabrics, catalysts for industry and order-of-magnitude faster computer chips.

Nanoscale Science and Engineering Funding
NSF Priority Area
(Dollars in Millions)

	FY 2004 Actual	FY 2005 Current Plan	FY 2006 Request	Change over FY 2005 Amount	Change over FY 2005 Percent
Biological Sciences	5.31	5.85	3.85	-2.00	-34.2%
Computer and Information Science & Engineering	17.56	18.48	5.00	-13.48	-72.9%
Engineering	108.88	127.77	127.77	0.00	0.0%
Geosciences	7.94	7.94	6.14	-1.80	-22.7%
Mathematical and Physical Sciences	111.48	131.62	95.82	-35.80	-27.2%
Social, Behavioral and Economic Sciences	2.59	1.56	1.56	0.00	0.0%
Office of International Science and Engineering	0.00	0.26	0.00	-0.26	-100.0%
Subtotal, Research and Related Activities	253.76	293.48	240.14	-53.34	-18.2%
Education and Human Resources	2.29	3.07	2.90	-0.17	-5.5%
Total, Nanoscale Science and Engineering	$256.05	$296.55	$243.04	-$53.51	-18.0%

Nanoscale science and engineering research promises a better understanding of nature, a new world of products beyond what it is now possible, high efficiency in manufacturing, sustainable development, better healthcare and improved human performance. The NNI began in FY 2001 (http://www.nano.gov). NSF's role in NNI emphasizes long-term, fundamental research aimed at discovering novel phenomena, processes, materials, and tools; supporting new interdisciplinary centers and networks of excellence; supporting research infrastructure, including shared user facilities; and addressing research and educational activities on the societal implications of advances in nanoscience and nanotechnology.

NSF has been a pioneer among federal agencies in fostering the development of nanoscale science, engineering and technology. It supports fundamental knowledge creation across all disciplinary principles at the nanoscale. In FY 2005, NSF has a budget for NS&E of $296.55 million for research in a wide range of research and education activities in nanoscale science and engineering. In FY 2006, funding for NS&E declines as new NNI activities transition from NS&E to NSF core research, consistent with the planned phase-out if the NS&E Priority Area. NSF's investment of $243.04 for NS&E will emphasize research aimed at discovering novel phenomena, processes, and tools and strengthening critical fields such as nanobiotechnology, nanomanufacturing, nanoelectronics, and catalysis at the nanoscale; modeling and simulation, supporting interdisciplinary centers and networks of excellence (including the National Nanotechnology Infrastructure Network and the Network for Computational Nanotechnology, both with

over 6500 users in FY 2006); a workforce to exploit opportunities presented by these new capabilities; and addressing activities with relevance to environment, health, education and other societal implications.

Support will encompass single investigator research, interdisciplinary research and education teams, national science and engineering centers, exploratory research and education projects, and education and training. The overarching ideas are reaching systematic control of phenomena at the nanoscale, exploitation of new phenomena and functions that do not extrapolate outside of the nanoscale domain, and use of the implications of such capabilities in areas of national interest. A dedicated theme for nanotechnology in the SBIR/STTR programs established in FY 2000 continues.

Long-term objectives include building a foundation of fundamental research for understanding and applying novel principles and phenomena for nanoscale manufacturing and other areas of relevance; ensuring that U.S. institutions will have access to a full range of nano-facilities; enabling access to nanotechnology education for the public through informal education, and for students in U.S. middle schools, secondary schools, colleges and universities; and catalyzing the creation of new commercial markets that depend on three-dimensional nanostructures. These goals will enable development of revolutionary technologies that contribute to improved human health, agricultural advancements, material and energy conservation, and sustainability in the environment.

Long-term Funding for NS&E at NSF

(Dollars in Millions)

FY 2001	FY 2002	FY 2003	FY 2004 Actual	FY 2005 Current Plan	FY 2006 Request	FY 2007[1]
$149.68	$192.28	$221.25	$256.05	$296.55	$243.04	$233.04

Estimates for 2007 and beyond do not reflect policy decisions and are presented for planning purposes only.

[1] FY 2007 will be the final year for the NS&E priority area.

Program Changes in FY 2006

Investments will be dedicated to research and education on:

- Active nanostructures, systems of nanosystems and molecular nanosystems. Research on nanoscale devices and system architecture, and their respective fabrication, will be emphasized;
- New tools for understanding and controlling assembling of materials and their emerging properties at the nanoscale;
- Converging science, engineering and technology from the nanoscale, and in particular at the nano-biology interface and nano-information interface;
- Long-term societal implications of nanotechnology in society, and public interaction;
- Earlier educational programs and teaching materials, including for K-12;
- Expand partnerships of academic researchers with industry, medical facilities and states through two programs, "Grand Opportunities for Academic Liaison with Industry" and "Partnerships for Innovation."

National Nanotechnology Initiative Funding
Federal Multiagency Initiative
(Dollars in Millions)

	FY 2004 Actual	FY 2005 Current Plan	FY 2006 Request	Change over FY 2005 Amount	Change over FY 2005 Percent
Biological Sciences	5.31	47.00	49.00	2.00	4.3%
Computer and Information Science & Engineering	17.56	18.48	12.00	-6.48	-35.1%
Engineering	108.88	127.77	127.77	0.00	0.0%
Geosciences	7.94	7.94	9.00	1.06	13.4%
Mathematical and Physical Sciences	111.48	132.14	141.54	9.40	7.1%
Social, Behavioral and Economic Sciences	2.59	1.56	1.56	0.00	0.0%
Office of International Science and Engineering	0.00	0.26	0.00	-0.26	-100.0%
Subtotal, Research and Related Activities	253.76	335.15	340.87	5.72	1.7%
Education and Human Resources	2.29	3.07	2.90	-0.17	-5.5%
Total, National Nanotechnology Initiative	$256.05	$338.22	$343.77	$5.55	1.6%

FY 2006 will likely see accelerated transition from scientific discoveries to technological innovation, as well as maintaining the pace of discoveries over the next year. Funding priority will be given to: (1) understanding and controlling the assembly of nanoscale materials, (2) research enabling the nanoscale as the most efficient manufacturing domain including fabrication of nanostructured materials and catalysts, (3) nanobiotechnology and nanobiomedicine, (4) innovative nanotechnology solutions to biological-chemical-radiological-explosive detection and protection, (5) understanding and potential application of quantum effects and other nanoscale phenomena, (6) nanoelectronics beyond complementary metal-oxide superconductors (CMOS) and nanophotonics, (7) development of new instrumentation and standards, and in particular for imaging, characterization and manipulation of materials and systems in three dimensions at the nanoscale, (8) education and training of a new generation for future industries, including high school, undergraduate, graduate and informal education through the Nanoscale Science and Engineering Education program solicitation. Three new networks expected to be selected through the FY 2005 solicitation, will become operational in FY 2006: the Center for Hierarchical Nanomanufacturing, the Center for Nanotechnology in Society, and the Center for Nanoscale Informal Education. These networks, together with the existing ones (NNIN, NCN and Nanoscale Center for Learning and Teaching) will establish a research and education platform for nanotechnology at the national level, including open and remote access based on merit review and clearing house opportunities at the national level.

FY 2006 NNI Funding. NSF's contributes to the goals and seven program component areas (PCAs) outlined in the NNI Strategic Plan:

1) Fundamental nanoscale phenomena and processes. The FY 2006 Request includes $95.0 million for fundamental research and education, with special emphasis on:

- *Novel phenomena, quantum control and basic engineering processes* – to discover and understand phenomena and design processes specific at the nanoscale, including new phenomena in materials, mechanics, chemistry, biology, electronics and optics. Potential applications include quantum computing and new devices and processes for advanced communications and information technologies.
- *Biosystems at the nanoscale* – to support study of biologically-based or -inspired systems that exhibit novel properties and potential applications. Potential applications include improved drug delivery, biocompatible nanostructured materials for implantation, exploiting of functions of cellular

organelles, devices for research in genomics, proteomics and cell biology, and nanoscale sensory systems, such as miniature sensors for early detection of cancer.

- *Converging science and engineering at the nanoscale* – The convergence of nanotechnology with information technology, modern biology and social sciences will reinvigorate discoveries and innovation in almost all areas of the economy. This theme includes investments in (a) Nano-biology interface and improving human performance, and (b) Nano-information interface research.
- *Multi-scale, multi-phenomena theory, modeling and simulation at the nanoscale* - to support theory, modeling, large-scale computer simulation and new design tools and infrastructure in order to understand, control and accelerate development in new nanoscale regimes and systems.

2) Nanomaterials. The FY 2006 Request includes $75.0 million for discovery of novel nanoscale and nanostructured materials and at gaining a comprehensive understanding of the properties of nanomaterials (ranging across length scales, and including interface interactions). Another focus will be on design and synthesis, in a controlled manner, of nanostructured materials with targeted properties. Research on the discovery, understanding and control of materials at the nanoscale will be critical to the development and success of innovative technologies including communications, energy, healthcare and manufacturing.

3) Nanoscale devices and systems. The FY 2006 Request includes $54.0 million for R&D that applies the principles of nanoscale science and engineering to create novel, or to improve existing, devices and systems. This includes the incorporation of nanoscale or nanostructured materials to achieve improved performance or new functionality, and developing new concepts to understand interactions among nanoscale devices in complex systems, including the physical, chemical, and biological interactions between nanostructures and device components. Interdisciplinary teams will investigate methods for design of systems composed of nanodevices.

Silicon nanotechnology and beyond CMOS is an area of focus. Research will explore ultimate limits to scaling of features and alternative physical principles for devices employed in sensing, storage, communication, and computation. The research activity in this area will help develop innovative technologies, including replacing electron charge as information carrier and bottom-up device assembly technologies at the atomic and molecular levels.

4) Instrumentation research for nanotechnology. The FY 2006 Request includes $11.80 million for R&D pertaining to create new tools needed to advance nanotechnology research and commercialization, including next-generation instrumentation for characterization, measurement, synthesis, and design of materials, structures, devices, and systems.

5) Nanomanufacturing. The FY 2006 Request includes $24.47 million to support new concepts for high rate synthesis and processing of nanostructures, nanostructured catalysts, fabrication methods for devices, and assembling them into nanosystems and then into larger scale structures of relevance in industry and in the medical field. R&D aimed at enabling scaled-up, reliable, cost effective manufacturing of nanoscale materials, structures, devices, and systems. It includes R&D and integration of ultra-miniaturized top-down processes, increasingly complex bottom-up or self-assembly processes, and developing novel concepts for high-rate synthesis and processing of nanostructures and nanosystems.

6) Major research facilities and instrumentation acquisition. The FY 2006 Request includes $24.0 million for establishment of user facilities, acquisition of major instrumentation, and other activities that develop, support, or enhance the scientific infrastructure for the conduct of nanoscale science, engineering, and technology research and development. It also supports ongoing operations of the National Nanotechnology Infrastructure Network and Network for Computational Nanotechnology. The investment will support facilities for 15 ongoing Nanoscale Science and Engineering Centers.

7) Societal Dimensions. The FY 2006 Request includes $59.50 million for various research and other activities that address the broad implications of nanotechnology for society, including benefits and risks, such as:

- Research directed at environmental, health, and safety impacts of nanotechnology development and basic research supporting risk assessment of such impacts ($24.0 million)
- Education-related activities, such as development of materials for schools, curriculum development for nanoscience and engineering, development of new teaching tools, undergraduate programs, technical training, and public outreach ($28.0 million) without including the educational component of student assistantships and fellowships in research awards
- Research directed at identifying and quantifying the broad implications of nanotechnology for society, including social, economic, workforce, educational, ethical, and legal implications ($7.50 million). The application of nanoscale technologies will stimulate far-reaching changes in the design, production and use of many goods and services. The implications of nanotechnology for society will be analyzed from social, behavioral, legal, ethical and economic perspectives. Factors that stimulate scientific discovery at the nanoscale will be investigated, effective approaches to ensure the safe and responsible development of nanotechnology will be explored and developed, and the potential for converging technologies to improve human performance will be addressed.

Coordination with Other Agencies

The NSF program is coordinated among 22 departments and agencies members through the National Science and Technology Council's subcommittee on Nanoscale Science, Engineering and Technology (NSET). NSET is chaired by an NSF staff member. Examples of specific coordination efforts are: Nanomanufacturing with DOD and NIST; Environmental issues with EPA and NIOSH; NSECs, NNIN and NCN centers and network with DOD, NASA and DOE; in modeling and simulation and nanoelectronics with DOD and NASA.

In the longer term, the capabilities of nanotechnology for systematic control and manufacture at the nanoscale are envisioned to evolve in four overlapping generations. Each generation of products is marked here by creation of first commercial prototypes through systematic control of the respective phenomena and the development of appropriate manufacturing processes, each requiring specific research emphasis: passive nanostructures, active nanostructures, three-dimensional nanosystems, and heterogeneous molecular nanosystems.