NATIONAL NANOTECHNOLOGY INITIATIVE (NNI)

NSF's contribution to the multiagency National Nanotechnology Initiative (NNI) encompasses the systematic understanding, organization, manipulation, and control of matter at the atomic, molecular, and supramolecular levels in the size range of 1 to 100 nanometers. Novel materials, devices, and systems – with their building blocks designed on the scale of nanometers – open up new directions in science, engineering, and technology with potentially profound implications for society. With the capacity to control and 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, order-of-magnitude faster computer chips, and sustainable development for water and energy resources utilization.

NNI by Program Component Area

(Dollars in Millions)

	FY 2010 Omnibus Actual	FY 2010 ARRA Actual	FY 2010 Enacted/ Annualized FY 2011 CR	FY 2012 Request
1. Fundamental Nanoscale Phenomena & Processes	$168.10	-	$152.57	$151.63
2. Nanomaterials	74.87	-	78.67	76.30
3. Nanoscale Devices & Systems	55.55	-	43.74	59.17
4. Instr. Research, Metrology, & Standards for Nanotech	17.88	-	18.34	16.58
5. Nanomanufacturing	21.41	-	22.43	57.20
6. Major Research Facilities & Instrumentation Acquisition	29.32	17.72	37.83	31.53
7. Environmental Health & Safety	27.05	-	24.34	34.51
8a. Education	28.64	-	28.44	23.75
8b. Societal Dimensions (ELSI)	5.85	-	5.85	5.28
Total, National Nanotechnology Initiative	**$428.67**	**$17.72**	**$412.21**	**$455.95**

Totals may not add due to rounding.

FY 2012 NNI Funding

NSF supports nanoscale science and engineering throughout all the research and education directorates as a means to advance discovery and innovation and integrate various fields of research. NNI enables increased interdisciplinarity at atomic and molecular levels for about 5,000 active awards, representing approximately 10 percent of NSF's portfolio. About 10,000 students and teachers will be educated and trained in nanoscale science and engineering in FY 2012. NSF contributes to the goals and eight program component areas (PCAs) outlined in the NNI Strategic Plan (www.nano.gov).

A portion of NSF's FY 2012 NNI funding is for the NNI Signature Initiatives. FY 2012 funding for the Nanoelectronics for 2020 and Beyond signature initiative is $50.0 million which is distributed in the Fundamental Nanoscale Phenomena and Processes, Nanomaterials, and Nanoscale Devices PCAs. These three PCAs also include FY 2012 funding of $32.0 million for the Nanotechnology for Solar Energy Collection and Conversion signature initiative. In addition, FY 2012 funding of $35.40 million for Sustainable Nanomanufacturing is contained within the Nanomanufacturing PCA.

In FY 2012, funds are transferred from several PCAs to increase funding for the Environmental, Health and Safety (EHS) PCA to reach a total FY 2012 funding level of $34.51 million. This shift reflects the prioritization of EHS within the overall NNI portfolio. Requests for research are primarily directed at environmental, health, and safety implications and methods for reducing the respective risks of

nanotechnology development. The support for EHS represents over 7.5 percent of total NNI funding at NSF. Overall NNI funding in the FY 2012 Request will increase by $43.74 million as compared to the FY 2010 Enacted primarily due to additional monies for the NNI Signature Initiatives.

NSF sponsored an international study on long-term research entitled "Nanotechnology Research Directions for Societal Needs in 2020" (NSF/WTEC 2010, Springer, available on www.nsf.gov/nano and www.wtec.org/nano2/. It provides assessment of nanotechnology development in the last ten years (2000-2010) and a long-term vision of the field in the next decade (2010-2020). This study evaluates the outcomes as recommended by the first report "Nanotechnology Research Directions: A vision for the next decade" (1999), adopted as an official document of the National Science and Technology Council (NSTC).

Fundamental Nanoscale Phenomena and Processes

The FY 2012 Request includes $151.63 million, which represents a decrease of $940,000 compared to the FY 2010 Enacted, for fundamental research and education. A part of those funds have transitioned to other PCAs, as part of the competitive planning process in each directorate. Special emphasis will be on:

- *Novel phenomena, quantum control, selfassembling, and basic engineering processes at the nanoscale*. – 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 information systems, novel products by multiscale self assembling, and new devices and sensors for industry and environmental monitoring. A new focus will be on understanding complex and emerging behavior of nanosystems, and creating nanomaterials and nanosystems by computational design.
- *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, food and plant systems, and nanoscale sensory systems, such as miniature sensors for early detection of cancer. A focus will be on the understanding of structure and function and simulation of cells, tissues, and nervous systems.
- *Converging science and engineering at the nanoscale* – to support the convergence of nanotechnology with information technology, modern biology, and social sciences – potentially reinvigorating discoveries and innovation in almost all areas of the economy. Examples are the nano-biology interface, the nano-information interface, and nano-neurosciences.
- *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. A special focus will be on simulations with atomic precision, time resolution of chemical reactions, and for domains of engineering and biological relevance.
- *NNI Signature Initiatives* -- to support the NNI Signature Initiatives, as well as planning for Nanotechnology for Regenerating the Human Body and Nanostructured Catalysts for Green Manufacturing.
- *Advanced Manufacturing Technologies* -- to support research in the Directorate for Computer and Information Science and Engineering (CISE) on advanced manufacturing technologies. A portion of this funding supports CISE's participation in the Nanoelectronics for 2020 and Beyond signature initiative.

Nanomaterials
The FY 2012 Request includes $76.30 million, a decrease of $2.37 million from the FY 2010 Enacted, for discovery of novel nanoscale and nanostructured materials, and improving the comprehensive understanding of the properties of nanomaterials (ranging across length scales and including interface interactions). A special focus will be 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 advances in electronics in Science and Engineering Beyond Moore's Law (SEBML), catalysts, energy, healthcare, and manufacturing.

Nanoscale Devices and Systems
The FY 2012 Request includes $59.17 million, an increase of $15.43 million from the FY 2010 Enacted, for R&D that applies the principles of nanoscale science and engineering to create novel, or to improve existing, devices and systems. The bulk of the increase over the FY 2010 Enacted – $15.0 million – is for advanced manufacturing technologies research in CISE, a portion of which will support CISE's participation in the Nanoelectronics for 2020 and Beyond signature initiative. A special focus will be on the architecture and emerging behavior of nanosystems, and on nanomanufacturing of active nanostructures and nanosystems. Nanoelectronics beyond silicon nanotechnology and complementary metal-oxide superconductors (CMOS) research will explore the 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, bottom-up device assembly technologies at the atomic and molecular levels, and new system architectures using nanoscale components. Another focus will be on building bio-systems and to regenerate the human body. An additional area of emphasis will be nano-informatics for better communication and nanosystem design.

Instrumentation Research, Metrology, and Standards for Nanotechnology
The FY 2012 Request includes $16.58 million for R&D, a decrease of $1.76 million from the FY 2010 Enacted, to create new tools needed to advance nanotechnology research and commercialization. Special challenges are developing tools for measuring and restructuring matter with atomic precision, for time resolution of chemical reactions, and for domains of biological and engineering relevance. Another focus is on developing on-line process instrumentation for nanoscale characteristics.

Nanomanufacturing
The FY 2012 Request includes an increase of $34.77 million above the FY 2010 Enacted, to $57.20 million, to support new concepts for high rate synthesis and processing of nanostructures, nanostructured catalysts, nanobiotechnology methods, 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 is aimed at enabling scaled-up, reliable, cost effective manufacturing of nanoscale materials, structures, devices, and systems. Advanced semiconductor and optical device design, fabrication and processing, for application in biomedical, alternative energy, communications, computing and sensing systems, will be pursued both through support of the centers and the core programs. The National Nanotechnology Initiative Signature Initiative: Nanoelectronics for 2020 and Beyond, will be supported for work on novel paradigms representing departures from traditional architectural practices of computing, including reconfigurable, evolvable, adaptive hardware architectures and the use of heterogeneous systems that can dynamically change via software mechanisms and architectures capable of combating error-prone devices at the nanoscale. The Foundation will strengthen the support for four NSECs (Nanoscale Science and Engineering Centers) that focus on manufacturing at the nanoscale. Those centers and the National Nanotechnology Infrastructure Network (NNIN) have strong partnerships with industry, national

laboratories, and international centers of excellence, which puts in place the necessary elements to bring discoveries in the laboratory to real-world, marketable innovations and technologies. The NSECs with a focus on nanomanufacturing are: the Center for Hierarchical Manufacturing (CHM); the Center for Scalable and Integrated Nanomanufacturing (SINAM); (c) the Center for High-rate Nanomanufacturing (CHN); and the Center for Nano-Chemical-Electrical-Mechanical Manufacturing Systems (Nano-CEMMS). NSF also supports the National Nanomanufacturing Network (NNN), which includes the NSF NSECs and non-NSF centers in collaboration with the Department of Defense (DOD), National Institute of Standards and Technology (NIST), and industry partners in an alliance to advance nanomanufacturing strength in the U.S. The FY 2012 Request increase is primarily associated with $35.40 million in additional funding for the signature initiative on Sustainable Nanomanufacturing.

Major Research Facilities and Instrumentation Acquisition
The FY 2012 Request includes $31.53 million, a decrease of $6.30 million from FY 2010 Enacted, for user facilities, acquisition of major instrumentation, and other activities that develop, support, or enhance the scientific infrastructure required for the conduct of nanoscale science, engineering, and technology research and development. It also supports ongoing operations of the National Nanotechnology Infrastructure Network (NNIN), the Network for Computational Nanotechnology (NCN), the National Network for Nanomanufacturing (NNN), and the National High Magnetic Field Laboratory (NHMFL). The networks are planned to have over 110,000 users in FY 2011. The investment will support facilities for 17 ongoing Nanoscale Science and Engineering Centers (NSEC). The FY 2012 funding decrease is due to the first class of six NSECs, initiated in 2001, receiving their final year of support in FY 2010 and other adjustments in the major research facilities. In addition, the FY 2012 Request will support the first class of three new Nanoscale Engineering Research Centers (Nanoscale ERCs).

Environmental, Health and Safety
The FY 2012 Request includes $34.51 million, an increase of $10.17 million over the FY 2010 Enacted, for research primarily directed at environmental, health, and safety (EHS) implications and methods for reducing the prospective risks of nanotechnology development. NSF, the Environmental Protection Agency (EPA), the U.S. Department of Agriculture (USDA), and the European Union (EU) will continue collaboration on development of a joint solicitation for nanotechnology EHS. A focus will be on implications of the next generation of nanotechnology products and productive processes, as well as public participation in nanotechnology related activities. Research on both implications and applications of nanotechnology will address the sources of nanoparticles and nanostructured materials in the environment (in air, water, soil, biosystems, and working environments), as well as the non-clinical biological implications. Research on the safety of manufacturing nanoparticles is included in seven NSECs and NNIN. Environmental implications of nanotechnology, including development of new measurement methods for nanoparticle characterization and toxicity of nanomaterials will be investigated in two dedicated multidisciplinary centers (Centers for Environmental Implications of Nanotechnology at UCLA and Duke University). These centers aim to conduct fundamental research on the interactions between nano-particles and materials and the living world at all scales. An essential element of this will be research on methods and instrumentation for nano-particle detection, characterization, and monitoring, including interactions of nano-materials with cellular constituents, metabolic networks and living tissues, bioaccumulation and its effects on living systems, and the impacts of nanostructures dispersed in the environment.

Education and Societal Dimensions
The FY 2012 Request includes $29.03 million for research and other activities that address the broad implications of nanotechnology for society, including education and social aspects, including:

- 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 ($23.75 million). Two networks for nanotechnology education with national outreach will be supported.
- Research directed at identifying and quantifying the broad implications of nanotechnology for society, including social, economic, workforce, educational, ethical, and legal implications ($5.28 million). The application of nanoscale technologies will stimulate far-reaching changes in the design, production, and use of many goods and services. NSF also supports a project to embed humanists and social scientists in nanoscience around the world, providing a model for future integration of ethicists and social scientists into nanotechnology R & D laboratories.

Coordination with Other Agencies

The NSF program is coordinated with 25 departments and agencies through the National Science and Technology Council's subcommittee on Nanoscale Science, Engineering and Technology (NSET). Examples of specific coordination efforts are: Nanomanufacturing (DOD/NIST); Environmental issues (EPA/ National Institute of Environmental Health Sciences (NIEHS)/USDA); NSECs, NNIN and NCN centers and networks (DOD/ National Aeronautics and Space Administration (NASA)/ Department of Energy (DOE)/ National Institutes of Health (NIH)); nanoelectronics (NIST, DOD), simulations in nanoelectronics (DOD/NASA); and research and training activities (DOD/NIH).

NNI Funding

(Dollars in Millions)

	FY 2010 Omnibus Actual	FY 2010 ARRA Actual[1]	FY 2010 Enacted/ Annualized FY 2011 CR	FY 2012 Request
Biological Sciences	$56.67	-	$56.60	$63.10
Computer and Information Science and Engineering	12.95	-	11.00	31.00
Engineering	152.50	17.72	148.00	174.37
Geosciences	0.85	-	0.85	0.85
Mathematical and Physical Sciences	199.11	-	190.59	182.36
Social, Behavioral and Economic Sciences	1.73	-	1.67	1.67
Office of International Science and Engineering	1.36	-	-	0.10
Subtotal, Research and Related Activities	$425.17	$17.72	$408.71	$453.45
Education and Human Resources	3.50	-	3.50	2.50
Total, National Nanotechnology Initiative	**$428.67**	**$17.72**	**$412.21**	**$455.95**

Totals may not add due to rounding.

[1] FY 2010 ARRA funding represents Major Research Instrumentation awards funded by Integrative Activities but managed by Engineering.