NATIONAL NANOTECHNOLOGY INITIATIVE

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, and order-of-magnitude faster computer chips.

National Nanotechnology Initiative Funding

(Dollars in Millions)

	FY 2008 Actual	FY 2009 Plan	FY 2009 ARRA Estimate	FY 2010 Request
Biological Sciences	$58.73	$56.60	-	$56.60
Computer and Information Science and Engineering	14.51	11.00	-	11.00
Engineering	144.45	140.02	35.00	148.00
Geosciences	10.29	6.33	-	6.33
Mathematical and Physical Sciences	173.73	178.06	72.81	195.86
Office of International Science and Engineering	0.50	-	-	-
Social, Behavioral and Economic Sciences	2.25	1.67	-	1.67
Subtotal, Research and Related Activities	$404.46	$393.68	$107.81	$419.46
Education and Human Resources	4.10	3.50	-	3.50
Total, National Nanotechnology Initiative	$408.56	$397.18	$107.81	$422.96

FY 2010 NNI Funding. NSF contributes to the goals and eight program component areas (PCAs) outlined in the NNI Strategic Plan (www.nano.gov). Environmental, health and safety implications of nanotechnology, including development of predictive toxicity of nanomaterials, will be investigated in three dedicated multidisciplinary centers and over other 50 smaller groups with a total annual budget of $29.9 million. The modes of support include single investigator, multidisciplinary team, center, and network awards.

Fundamental Nanoscale Phenomena and Processes. The FY 2010 Request includes $154.74 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. A focus will be on the understanding and use of self assembly from basic principles and on multiple scales. Potential applications include use of quantum phenomena in systems and quantum computing, and new devices and processes for advanced communications and information technologies. A new program on "Macromolecular, Supramolecular and Nanostructures" will be established.
- *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 understanding and simulation of cells, tissues, and nervous systems, with application to biomedicine and neuromorphic engineering.

- *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, (b) nano-information interface research, and (c) 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. Another focus will be on predictive methods of nanomaterials' macroscopic properties from their nanostructure.

Nanomaterials. The FY 2010 Request includes $80.44 million 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 gaining control of nanoscale features and devices with an atomic level of precision. Another 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 communications, catalysts, energy, healthcare, and manufacturing. An example is the Caltech center for nanomaterials for alternative energy applications focus on developing the components for a solar water splitting system.

Nanoscale Devices and Systems. The FY 2010 Request includes $43.77 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. 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 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.

A special focus will be on nano-informatics for better communication and nanosystem design. It includes defining the ontology of terms, interconnecting databases, using specific informatics tools, and connecting to bioinformatics.

Instrumentation Research, Metrology, and Standards for Nanotechnology. The FY 2010 Request includes $18.52 million for R&D 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. A special challenge is developing tools for measuring and restructuring matter with atomic precision, for time resolution of chemical reactions, and for domains of biological and engineering relevance.

Nanomanufacturing. The FY 2010 Request includes $22.45 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. A special focus will be creating active nanostructures and complex nanosystems. This will include 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.

Major Research Facilities and Instrumentation Acquisition. The FY 2010 Request includes $38.47 million for 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 (NNIN), Network for Computational Nanotechnology (NCN), National Network for Nanomanufacturing (NNN), and National High Magnetic Field Laboratory (NHMFL). The networks are planned to have over 90,000 users in FY 2010. The investment will support facilities for 17 ongoing Nanoscale Science and Engineering Centers (NSEC).

Environmental, Health and Safety. The FY 2010 Request includes $29.90 million, an increase of $1.99 million over the FY 2009 Plan for research primarily directed at environmental, health, and safety (EHS) implications and methods for reducing the respective risks of nanotechnology development. NSF, the Environmental Protection Agency (EPA), the U.S. Department of Agriculture (USDA), and the European Union (EU) will collaborate for the preparation of a joint solicitation on nano EHS in FY 2010. Basic research will support understanding of underlying phenomena and processes. 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 environment), as well as the non-clinical biological implications. The safety of manufacturing nanoparticles is investigated in eight centers: NSEC at Rice University (evolution of manufacturing nanoparticles in the wet environment), NSEC at Northeastern University (occupational safety during nanomanufacturing), NSEC at University of Pennsylvania (interaction between nanomaterials and cells), NSEC at University of Wisconsin, Madison (effect of nanostructured polymers on EHS), NSEC at University of California, Berkeley (building a system for detecting exposure to individual and portable nanomaterials), NSEC at the University of Ohio (nanoscale devices for monitoring and healing), NSEC at University of Massachusetts, Amherst, (clearinghouse on occupational safety), and National Nanotechnology Infrastructure Network (with two nanoparticle characterization centers at the University of Minnesota and Arizona State University). 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). It aims 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. This work will support regulatory and mission agencies in developing science-based standards for risk assessments, such as those needed by the National Institute of Standards and Technology (NIST), EPA, the Food and Drug Administration (FDA) and other agencies to develop standards for and to regulate nano-materials. NSF will provide supplements to NSECs for nano EHS on a competitive basis.

Education and Societal Dimensions. The FY 2010 Request includes $34.67 million, an increase of $2.60 million over the FY 2009 Plan, for various research and other activities that address the broad implications of nanotechnology for society, including education and social aspects, such as:

- 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 ($28.04 million). Two networks for nanotechnology education with national outreach will be supported: The Nanotechnology Center for Learning and Teaching (NCLT) and the Network for Nanoscale Informal Science Education (NISE).
- Research directed at identifying and quantifying the broad implications of nanotechnology for society, including social, economic, workforce, educational, ethical, and legal implications ($5.78 million). The application of nanoscale technologies will stimulate far-reaching changes in the design, production, and use of many goods and services. 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. The Nanotechnology in Society Network will extend its national and international network.
- NSF will support activities of a new Society for the Study of Nanoscience and Emerging Technologies with an international network of researchers, students, stakeholders, and policymakers. A study to assess and compare the capability of research centers in nanotechnology and other emerging technologies to integrate broader societal considerations and social sciences into their work. This study is coordinated with a European effort using the same methodology.

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 (Department of Defense (DOD)/NIST); Environmental issues (EPA/ National Institute of Environmental Health Sciences (NIEHS)/USDA); NSECs, NNIN and Network for Computational Nanotechnology (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 by Program Component Area

(Dollars in Millions)

	FY 2008 Actual	FY 2009 Plan	FY 2009 ARRA Estimate	FY 2010 Request
1. Fundamental Nanoscale Phenomena & Processes	$154.28	$146.42	$38.52	$154.74
2. Nanomaterials	72.87	74.59	27.74	80.44
3. Nanoscale Devices & Systems	44.63	42.26	9.16	43.77
4. Instr. Research, Metrology, & Standards for Nanotech	21.78	17.61	3.37	18.52
5. Nanomanufacturing	20.71	21.90	3.20	22.45
6. Major Research Facilities & Instrumentation Acquisition	29.14	34.42	17.73	38.47
7. Environmental Health & Safety	29.22	27.91	2.69	29.90
8a. Education	28.55	26.60	4.96	28.79
8b. Societal Dimensions (ELSI)	7.38	5.47	0.44	5.88
Total, National Nanotechnology Initiative	$408.56	$397.18	$107.81	$422.96

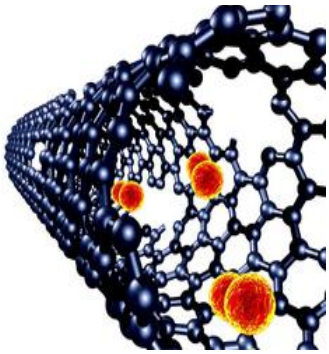
Totals may not add due to rounding.

Recent Research Highlights

► **Safer by the Sip:** The discovery of unexpected magnetic interactions between ultra-small specks of rust is leading scientists at Rice University's Center for Biological and Environmental Nanotechnology to develop a revolutionary, low-cost technology for cleaning arsenic from drinking water. Nanoparticles of iron oxide (magnetite) can remove 200 times more arsenic from water than the same mass of larger commercial materials. The technology holds promise for millions of people in India, Bangladesh, and other developing countries where thousands of cases of arsenic poisoning each year are linked to poisoned wells. When prepared in a nanocrystalline form, magnetite not only soaks up more arsenic, most likely due to the larger available surface area of the nanomagnets, it also binds more strongly, resulting in less desorption of arsenic. Researchers hope results will lead to better water treatment solutions.

Arsenic binds easily to iron oxide nanocrystals allowing it to be removed from drinking water when the "nano-rust" is fished out of solution by a low-field magnet. *Credit: Center for Biological and Environmental Nanotechnology.*

► **New Type of Nanotube Capsules Offer Safer, More Precise Medical Images:** Reducing the toxicity of medical imaging agents is critical to improving the delivery of medical services. Rice University researchers developed the first water-soluble, nanotube-based biocompatible contrast agent for use in computed tomography (CT) X-ray imaging. The new tool sequesters the medical imaging agent safely inside an ultra-short nanotube capsule. The new tool also offers the potential to detect disease at the cellular level when it is most treatable. Current imaging agents are designed to remain outside of cells and to clear from the body quickly due to their high toxicity. The new technology loads iodine, the imaging agent, inside single-walled carbon nanotubes that have been modified to make them more compatible with the human body. The agent can be used inside cells and for long periods due to its reduced toxicity and water solubility.



Ultra-short, single-walled carbon nanotubes can be loaded with contrast agents for enhanced medical imaging. *Credit: Center for Biological and Environmental Nanotechnology.*