NATIONAL NANOTECHNOLOGY INITIATIVE (NNI)

Total Funding for NNI
(Dollars in Millions)

	FY 2016 Actual	FY 2017 (TBD)	FY 2018 Request
Biological Sciences	$48.80	-	$42.50
Computer and Information Science and Engineering	13.55	-	12.10
Education and Human Resources	2.50	-	2.50
Engineering	207.50	-	168.50
Geosciences	0.30	-	-
Mathematical and Physical Sciences	237.10	-	162.53
Social, Behavioral, and Economic Sciences	0.53	-	0.40
Office of International Science and Engineering	0.10	-	0.10
Total, NNI	**$510.38**	**-**	**$388.63**

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 about 1 nanometer 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 researchers are realizing revolutionary advances in areas such as order-of-magnitude faster computers with less energy consumption; catalysts for industry; molecular medicine; imaging and understanding of the brain; nanosensors to monitor health and the environment; efficient and large-scale nanomanufacturing; more resilient materials and system architectures; and sustainable development for water, energy, and food resource utilization. NSF contributes to the NNI goals and five Program Component Areas (PCAs) outlined in the 2016 NNI Strategic Plan and the NNI Supplement to the President's Budget for Fiscal Year 2017.[18] Funding by PCA is shown at the end of this discussion.

FY 2018 NNI Funding

NSF supports nanoscale science and engineering throughout all the research and education directorates as a means to advance discovery, invention, and innovation and to integrate various fields of research. NNI enables increased interdisciplinarity at atomic and molecular levels for about 6,000 active awards with full or partial contents on nanoscale science and engineering (NSE). Approximately 10,000 students and teachers will be educated and trained in NSE in FY 2018.

Overall, total NNI funding in the FY 2018 Request is $388.63 million. Several new directions planned for FY 2018 are nanotechnology for brain-like computing, including highly energy efficient systems and intelligent cognitive assistants; nanobiomanufacturing, including cell technology; food-energy-water processes, including nanofiltration at end-users; nanomodular materials and systems by design, including three-dimensional nanoscale materials; and emerging aspects of nanoelectronics, photonics, papertronics, and neuroscience. NSF sponsors an annual NSE grantee conference to assess the progress in nanotechnology and facilitate identification of new research directions.[19]

[18] www.nano.gov
[19] 2016 Nanoscale Science and Engineering Grantees Conference: www.nsf.gov/nano and www.nseresearch.org/2016/

In FY 2018, NSF support will increasingly focus on convergence research and education activities in confluence with other priority areas such as: Networking and Information Technology Research and Development (NITRD) and the National Strategic Computing Initiative (NCSI); Science, Engineering, and Education for Sustainable Chemistry, Engineering and Materials (SusChEM); Designing Materials to Revolutionize and Engineer our Future (DMREF); Materials Genome Initiative; Smart Systems; Quantum Information Science and Engineering; and synthetic biology. Partnerships of new Nanoscale Engineering Research Centers (NERCs) with small businesses in the areas of nanomanufacturing and commercialization will be strengthened while maintaining about the same level of NSF investment. A new industrial internship in emerging nanotechnology areas is planned with IBM. NSF continues its contributions to translational innovation programs, including Grant Opportunities for Academic Liaison with Industry (GOALI); Industry/University Cooperative Research Centers (I/UCRC); the NSF Innovation Corps (I-Corps™) program; and the two subcomponents of Partnerships for Innovation (PFI): Accelerating Innovation Research (AIR) and Building Innovation Capacity (BIC). The NSF Small Business Innovation Research (SBIR) program has an ongoing nanotechnology topic with subtopics for nanomaterials, nanomanufacturing, nanoelectronics and active nanostructures, nanotechnology for biological and medical applications, and instrumentation for nanotechnology. Nanotechnology research will contribute and synergize in the future with eight of NSF's Big Ideas.

Various assessments and reports have assisted with informing plans for NNI going into the future. NSF sponsored an international study on long-term research entitled *Nanotechnology Research Directions for Societal Needs in 2020.*[20] It provides an assessment of nanotechnology development in the ten year period (2000-2010) and a vision of the field for the following decade (2010-2020). This study evaluates the outcomes recommended by the first report issued in 1999, *Nanotechnology Research Directions: A vision for the next decade*, which was adopted as an official document of the National Science and Technology Council (NSTC). With the National Institutes of Health (NIH), National Aeronautics and Space Administration (NASA), Environmental Protection Agency (EPA), Office of Naval Research (ONR), and the U.S. Department of Agriculture (USDA), NSF co-sponsored the study entitled *Converging Knowledge, Technology, and Society*[21] evaluating the convergence of nanotechnology with other emerging areas. A follow-up report on *Science and Technology Convergence* was completed in 2016. A study on *Nanomodular Materials and Systems by Design* to identify international activities and research directions was completed in 2016.[22] The 2016 reports *Energy-Efficient Computing from Devices to Architectures* and *Intelligent Cognitive Assistants* were completed in collaboration with the Semiconductor Industry Association (SIA) and the Semiconductor Research Corporation (SRC). The purpose of these reports was to define Grand Challenges, one of them being Brain-like Computing. The reports address aspects of fundamental research for energy-efficient sensing and computing, data storage, real-time communication ecosystem, multi-level and scalable security, a new fabrication paradigm, and insight computing. [23,24]

Program Component Areas (PCAs) are the major subject areas of relevance to the NNI agencies, where progress is critical to achieving the NNI's goals and to realizing its vision.[25] NSF supports funding in all five PCAs.

PCA 1: Nanotechnology Signature Initiatives (NSIs)
The first PCA, which encompasses the five Nanotechnology Signature Initiatives (NSIs), will be funded at a total of $106.87 million. The Water Sustainability through

[20] NSF/WTEC 2010, Springer, available on www.nsf.gov/nano and www.wtec.org/nano2/
[21] NSF/WTEC 2013, Springer, available on www.nsf/gov/nano and www.wtec.org/NBIC2-Report/
[22] www.wtec.org/nmsd/
[23] http://1.usa.gov/1Fg90Dw; https://www.src.org/nri/energy-efficient-computing-workshop.pdf
[24] www.semiconductors.org/issues/research/research/
[25] www.nano.gov/nni-pca

Nanotechnology NSI began in FY 2016 and will continue in FY 2018. Special emphasis will be on:

- Sustainable Nanomanufacturing ($29.77 million)—Establishing manufacturing technologies for economical and sustainable integration of nanoscale building blocks into complex, large-scale systems by supporting product, tool, and process design informed by and adhering to the overall constraints of safety, sustainability, and scalability. This signature initiative specifically focuses on high-performance structural carbon-based nanomaterials, optical metamaterials, cellulosic nanomaterials, nanobiomanufacturing and nanomodular systems. This initiative will establish manufacturing technologies for economical and sustainable integration of nanoscale building blocks into complex, large-scale systems. A program solicitation, *Scalable Nanomanufacturing for Integrated Systems,* and a DCL, *Advanced Manufacturing Research to Address Basic Research Enabling Innovation at Manufacturing USA Institutes,* are planned for 2017 and 2018. Engineering biology at the nanoscale for advanced manufacturing activities in the Directorates for Biological Sciences (BIO), Engineering (ENG), and Mathematics and Physical Sciences (MPS) are being organized for 2017 and 2018. Methods for nanomanufacturing design are in synergy with the Materials Genome Initiative.
- Nanoelectronics for 2020 and Beyond ($37.35 million)—This initiative is aimed at discovering and using novel nanoscale fabrication processes and innovative concepts to produce revolutionary materials, devices, systems, and architectures to advance the field of electronics beyond Moore's Law. Collaboration in the Nanoelectronics Research Initiative with SRC (n-CORE, STARnet, nanobio) and the National Institute of Standards and Technology (NIST) is planned to continue in 2017 and 2018 with a focus on *Energy Efficiency Devices, Systems and Architectures (E2CDA*). Research is planned on the NNI Grand Challenge *Brain-like Computing* and *Intelligent Cognitive Assistants*. Two examples of active centers are the Science and Technology Center (STC) on Quantum Materials and Devices at Harvard University and the Materials Research Science and Engineering Center (MRSEC) on Quantum and Spin Phenomena in Nanomagnetic Structures at the University of Nebraska, Lincoln. NSF will increase coordinated research on Quantum leap, one of the NSF's Big Ideas.
- Nanotechnology Knowledge Infrastructure ($19.68 million)—Activities surrounding the fundamental, interconnected elements of collaborative modeling and computer simulation, an interacting cyber-toolbox, and data infrastructure for nanotechnology. This initiative aims to provide a community-based, solution-oriented knowledge infrastructure for discovery, innovation, and nanoinformatics of research, education and regulatory interest to NNI agencies. The Network for Computational Nanotechnology (NCN) conducts key activities in support to this NSI and has been re-competed for 2017-2022. Program solicitations, "Cyber-Enabled Discovery and Innovation" and "Software Infrastructure for Sustained Innovation", will contribute to data infrastructure, software advances, and high throughput computation.
- Nanotechnology for Sensors and Sensors for Nanotechnology ($8.64 million)—Use of nanotechnology and nanoscale materials to build more sensitive, specific, and adaptable sensors and the development of new sensors to detect engineered nanomaterials across their life-cycles to assess their potential impacts. This initiative supports materials and technologies that enable new sensing of biological, chemical, and nanoscale materials, including sensors for nano environment, health, and safety (nano-EHS). A dedicated program on nanobiosensors and biophotonics in the Division of Chemical, Bioengineering, Environmental, and Transport Systems (CBET) in ENG will support this effort.
- Water Sustainability through Nanotechnology ($11.43 million)—Takes advantage of the unique properties of engineered nanomaterials and systems to increase water availability; improve the efficiency of water delivery; and enable next-generation water monitoring systems. The Innovations at the Nexus of Food, Energy, and Water Systems (INFEWS) initiative supports projects in nanotechnology. Besides core nanoscience-related programs on water filtration and applications, the NERC for Nanotechnology Enabled Water Treatment Systems (NEWT) led by Rice University, funded between 2015 and 2020, aims at developing high-performance water treatment systems that will: broaden access to clean drinking water from a variety of unconventional sources (briny well water,

seawater, wastewater), and enable industrial wastewater reuse at remote locations such as oil and gas fields.

PCA 2: Foundational Research
The FY 2018 Request includes $190.17 million for the discovery and development of fundamental knowledge pertaining to new phenomena in the physical, biological, and engineering sciences that occur at the nanoscale. Also included is funding for research aiming to understand scientific and engineering principles related to nanoscale systems, structures, processes, and mechanisms; research on the discovery and synthesis of novel nanoscale and nanostructured materials including biomaterials and modular structures; and research directed at identifying and quantifying the broad implications of nanotechnology for society, including social, economic, ethical, and legal implications. About 60 percent of the MRSECs pursue NSE-related fundamental research.

PCA 3: Nanotechnology-Enabled Applications, Devices, and Systems
The FY 2018 Request includes $37.90 million for research that applies the principles of nanoscale science and engineering to create novel devices and systems, or to improve existing ones. This includes the incorporation of nanoscale or nanostructured materials and the processes required to achieve improved performance or new functionality, including metrology, scale up, manufacturing technology, and nanoscale reference materials and standards. Core programs in ENG, Computer and Information Science and Engineering (CISE) and MPS support development of new principles, design methods and constructive solution for nanodevices. A special focus is on smart autonomous nanoscale-based devices and systems.

PCA 4: Research Infrastructure and Instrumentation
The FY 2018 Request includes $42.59 million for the establishment and operation of user facilities and networks, acquisition of major instrumentation, workforce development, and other activities that develop, support, or enhance the Nation's physical or human infrastructure for nanoscale science, engineering, and technology. This PCA includes research pertaining to the tools needed to advance nanotechnology research and commercialization, including next-generation instrumentation for characterization, measurement, synthesis, and design of materials, structures, devices, and systems. While student support to perform research is captured in other categories, dedicated educational and workforce efforts, ranging from curriculum development to advanced training, are included here as resources supporting the human infrastructure of the NNI. NSF funded an award of about $16 million per year for the National Nanotechnology Coordinated Infrastructure (NNCI) sites for 2015-2020, whose national coordination office was added in FY 2016. Other STC, ERC, and MRSECs have a focus supporting NNI such as the Center for Cellular Construction at the University of California-San Francisco (annual award since 2016 is approximately $5 million) and two NERC on nanobio and cell technology. NSF continues to sponsor nanotechnology education and related activities, such as disseminating the video series with NBC Learn, *Nanotechnology: Super Small Science*. Other examples are high-school student competitions "Video nanotechnology student competition" and "Generation Nano" sponsored by ENG, MPS and the NSF Office of Legislative and Public Affairs.[26]

PCA 5: Environment, Health, and Safety
In FY 2018, NSF will continue its funding for the Environment, Health, and Safety (EHS) PCA at $11.10 million, representing roughly 2.8 percent of its overall NNI budget. Requests for research are primarily directed at understanding nano-bio phenomena and processes, as well as environment, health, and safety implications and methods for reducing the respective risks of nanotechnology development. NSF continues to sponsor two Centers for Environmental Implications of Nanotechnology at the University of California, Los Angeles (UCLA) and Duke University. The Nano EHS Program within the Engineering Directorate has changed to *Biological and Environmental Interactions of Nanoscale Materials.*

[26] www.nsf.gov/news/special_reports/gennano/index.jsp

Coordination with Other Agencies

The NSF NNI program is coordinated with 20 departments and agencies through the NSTC subcommittee on Nanoscale Science, Engineering and Technology (NSET). These agencies also partner with NSF to sponsor joint workshops on nanotechnology research directions and send representatives to participate in grantees conferences. Some specific coordination efforts are:

- Sustainable Nanomanufacturing—NSF with the National Institute of Standards and Technology (NIST), Department of Energy (DOE), EPA, NIH, National Institute for Occupational Safety and Health (NIOSH), Occupational Safety and Health Administration (OSHA), USDA/Food Safety (FS);
- Collaboration with the NIST, Air Force Office of Scientific Research (AFOSR) Defense Advanced Research Projects Agency (DARPA), and SRC (n-CORE, STARnet) to continue in 2017 and 2018 with a focus on "Energy Efficiency Devices, Systems and Architectures (E2CDA)" and "Brain-like Computing";
- Nanoelectronics—NIST, Department of Defense (DOD), DOE, Intelligence Community (IC)/Director of National Intelligence (DNI), and NASA;
- NNCI and NCN centers and networks—NSF with DOD, NASA, DOE, and NIH;
- Nanosensors—collaboration with NIOSH, NIH, FDA, NIST, DOD, NASA, NSF, and EPA;
- Innovations at the Nexus of Food, Energy and Water Systems (INFEWS) program—NSF and USDA/NIFA joint solicitation;
- NSF collaboration with NIOSH, National Cancer Institute (NCI), NIH, NIST, Pacific Northwest National Laboratory, and DOD, and many public- and private-sector partners with the Nanoinformatics Consortium: UCLA, the National Nanomanufacturing Network, nanoHUB, RTI International, MIT, and the NanoBusiness Commercialization Association.
- Organization for Economic Cooperation and Development (OECD) (Working Group on Bio, Nano, and other Converging Technologies) and other international forum activities—participation by NSF in collaboration with State Department and other NNI agencies.

NNI Funding by Program Component Area

(Dollars in Millions)

	FY 2016 Actual	FY 2017 (TBD)	FY 2018 Request
1. Nanotechnology Signature Initiatives	$163.59	-	$106.87
Sustainable Nanomanufacturing	*37.22*	-	*29.77*
Nanoelectronics for 2020 and Beyond	*70.31*	-	*37.35*
Nanotechnology Knowledge Infrastructure	*23.86*	-	*19.68*
Nanotechnology for Sensors	*16.29*	-	*8.64*
Water Sustainability through Nanotechnology	*15.91*	-	*11.43*
2. Foundational Research	216.85	-	190.17
3. Nanotechnology-Enabled Applications, Devices, and Systems	55.87	-	37.90
4. Research Infrastructure and Instrumentation	56.51	-	42.59
5. Environment, Health, and Safety	17.56	-	11.10
Total, NNI	**$510.38**	**-**	**$388.63**