NATIONAL NANOTECHNOLOGY INITIATIVE (NNI)
NSF, FY 2021 REQUEST

Total Funding for NNI

(Dollars in Millions)

	FY 2019 Actual	FY 2021 Request
BIO	$42.50	$39.95
CISE	13.50	13.08
EHR	2.53	2.50
ENG	218.35	199.00
MPS	243.34	199.00
SBE	0.40	-
IA	0.10	-
Total	**$520.72**	**$453.53**

Overview

NSF's contribution to the multiagency 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; quantum qubits and systems; nanosensors to monitor health, the environment, human-machine interactions, and input to artificial intelligent (AI) systems; 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 2019.[1] Funding by PCA is shown at the end of this discussion. Funding for the Nanotechnology Signature Initiative (NSI) on Nanotechnology Knowledge Infrastructure continued through the end of FY 2019, without additional funding for FY 2021.

FY 2021 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 in areas of atomic and molecular research in 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 2021.

Overall, NSF's total NNI funding in the FY 2021 Request is $453.53 million. Several new directions planned for FY 2021 are nanotechnology for using artificial intelligence (AI) for nanomaterial and nanosystem design and enabling AI systems, sustainable nanotechnology for micro and nano particles, brain-like computing and advancing human-technology frontier, including highly energy efficient systems and intelligent cognitive assistants; nanobiomanufacturing, including nanobiomotors and cell technology;

[1] www.nano.gov

food-energy-water processes, such as nanofiltration at end-users; nanomodular materials and systems by design, including quantum structures and three-dimensional nanoscale materials; emerging aspects of nanoelectronics, photonics, use of artificial intelligence for smart materials and systems, and neuroscience; and convergence of nanotechnology with other emerging S&E fields. NSF sponsors an annual NSE grantee conference to assess the progress in nanotechnology and facilitate identification of new research directions.[2]

In FY 2021, 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); Science, Engineering, and Education for Sustainable Chemistry, Engineering and Materials (SusChEM); A new NNI Strategic Plan is planned to be approved in 2021 by the Administration and be submitted to Congress. Designing Materials to Revolutionize and Engineer our Future (DMREF); Materials Genome Initiative; Smart Systems; Quantum Information Science and Engineering; AI; and synthetic biology. NSF will strengthen partnerships of the Nanoscale Engineering Research Centers (NERCs) with small businesses in the areas of nanomanufacturing and commercialization, and support an industrial internship program (INTERN) in emerging areas. NSF continues its contributions to translational innovation programs, including Grant Opportunities for Academic Liaison with Industry (GOALI); Industry-University Cooperative Research Centers (IUCRC); the NSF Innovation Corps (I-Corps™) program; and the Partnerships for Innovation (PFI). 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, and particularly with QL, URoL, FW-HTF, HDR, and GCR.

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*,[3] which provides a vision of the field to 2020 and beyond. 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*[4] evaluating the convergence of nanotechnology with other emerging areas by 2030. Other 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.[5,6,7]

PCAs are the major subject areas of relevance to the NNI agencies, where progress is critical to achieving NNI's goals and to realizing its vision.[8] NSF supports funding in all five PCAs.

PCA 1: Nanotechnology Signature Initiatives (NSIs) and Grand Challenges (GCs)

The first PCA, which encompasses the four, beginning in FY 2021—Nanotechnology Signature Initiatives (NSIs) and Grand Challenge, will be funded at a total of $100.42 million. The Water Sustainability through Nanotechnology NSI began in FY 2016 and will continue in FY 2021. The Nanotechnology-Inspired Grand Challenge for Future Computing began in FY 2017. Special emphasis will be on:

- Sustainable Nanomanufacturing ($32.0 million) ―Establishing manufacturing technologies for economical and sustainable integration of nanoscale building blocks into complex, large-scale systems

[2] 2019 Nanoscale Science and Engineering Grantees Conference: www.nsf.gov/nano and www.nseresearch.org/2019/
[3] NSF/WTEC 2010, Springer, available on www.nsf.gov/nano and www.wtec.org/nano2/
[4] NSF/WTEC 2013, Springer, available on www.nsf.gov/nano and www.wtec.org/NBIC2-Report/
[5] www.nsf.gov/nano
[6] 1.usa.gov/1Fg90Dw; www.src.org/nri/energy-efficient-computing-workshop.pdf
[7] www.semiconductors.org/issues/research/research/
[8] www.nano.gov/about-nni/what/vision-goals

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 hierarchical nanomanufacturing, high-performance structural carbon-based nanomaterials, optical metamaterials, cellulosic nanomaterials, nanobiomanufacturing and nanomodular systems. Engineering biology at the nanoscale for advanced manufacturing activities in BIO, ENG, and MPS are being organized for 2021. Methods for nanomanufacturing design are in synergy with the Materials Genome Initiative. A new direction is manufacturing of quantum systems, nanomachines and Nano biostructures.

- Nanoelectronics for 2020 and Beyond ($34.0 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 with SRC (n-CORE, STARnet, nanobio) and the National Institute of Standards and Technology (NIST) is planned to continue in 2021 with a focus on new concepts for *energy-efficient devices and architectures and Semiconductor Synthetic Biology for Information Processing and Storage Technologies (SemiSynBio)*. NSF will increase coordinated research on QL and the FW-HTF.
- Nanotechnology for Sensors and Sensors for Nanotechnology ($8.50 million) ―This initiative funds the 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). Dedicated programs on biosensing and biophotonics in ENG's Division of Chemical, Bioengineering, Environmental, and Transport Systems (CBET) will support this effort.
- Water Sustainability through Nanotechnology ($13.0 million) ―This initiative 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. 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 2025, 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.
- Nanotechnology-Inspired Grand Challenge for Future Computing ($12.92 million) ―Research is planned on the NNI Grand Challenge related research on "Brain-like Computing" and "Intelligent Cognitive Assistants" (ICA). Two examples of active centers are the Science and Technology Center (STC) on Integrated Quantum Materials 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 plans to sponsor research on ICA as part of program announcements for two NSF Big Ideas: FW-HTF and GCR. Further collaboration is planned with industry groups developing hardware (with a focus on a "beyond Moore" system architecture and corresponding devices), software (with a focus on artificial intelligence), and implementing in various applications. The research will be conducted in collaboration with other agencies (NIH, Defense Advanced Research Projects Agency (DARPA)).

PCA 2: Foundational Research

The FY 2021 Request includes $258.44 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. It will support activities surrounding the fundamental, interconnected elements of collaborative modeling and computer simulation, an

interacting cyber-toolbox, and data infrastructure for nanotechnology. The Network for Computational Nanotechnology (NCN) conducts key activities in support to this PCA with about 1.4 million users per year and has been awarded an extension to 2022. About 60 percent of the MRSECs pursue NSE-related fundamental research.

PCA 3: Nanotechnology-Enabled Applications, Devices, and Systems

The FY 2021 Request includes $50.75 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, 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 2021 Request includes $33.40 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 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. The FY 2021 Request for this is funded at $13.71 million. Other STC, ERC, and MRSECs have a focus supporting NNI such as the STC Center for Cellular Construction at the University of California-San Francisco (annual award since 2016 is approximately $5 million) and two NERCs, one each on nano-bio 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 example is the student competition "Quantum Matters" Communication Competition" for undergraduate and graduate students,[9] nation-wide, with the participation of the Boston Museum of Science. NSF will increase coordinated research on Mid-Scale Research Infrastructure.

PCA 5: Environment, Health, and Safety

In FY 2021, NSF will continue its funding for the Environment, Health, and Safety (EHS) PCA at $10.52 million, representing roughly three 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. ENG's Nano EHS Program has changed to *Biological and Environmental Interactions of Nanoscale Materials*. MPS supports the Center for Chemical Innovation (CCI): Center for Sustainable Nanotechnology. NSF is planning to issue a DCL on "Micro-and Nanoplastics" for awards to be made in FY 2020 and FY 2021.

Coordination with Other Agencies

NSF's NNI program is coordinated with 32 other departments and agencies through the National Science and Technology Council subcommittee on Nanoscale Science, Engineering and Technology (NSET). These agencies also partner with NSF to sponsor joint funding activities and workshops on nanotechnology research directions and send representatives to participate in grantees conferences. Some specific

[9] www.mos.org/quantum-matters-competition

coordination efforts are:

- Sustainable Nanomanufacturing—NSF, 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 NIST, Air Force Office of Scientific Research (AFOSR), and DARPA will continue in 2020 with a focus on "Brain-like Computing";
- Nanoelectronics—NSF, NIST, Department of Defense (DOD), DOE, Intelligence Community (IC)/Director of National Intelligence (DNI), and NASA;
- NSF collaborates with other 12 other agencies in the NNI task force on "Nanoplastics";
- NNCI and NCN centers and networks—NSF, DOD, NASA, DOE, and NIH;
- Nanosensors—NSF, NIOSH, NIH, FDA, NIST, DOD, NASA, and EPA;
- INFEWS program—NSF and USDA/NIFA joint solicitation;
- NSF collaboration with NIOSH, NIH's National Cancer Institute (NCI), 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.
- 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 2019 Actual	FY 2021 Request
1. Nanotechnology Signature Initiatives	$150.92	$100.42
Sustainable Nanomanufacturing	*40.10*	*32.00*
Nanoelectronics for 2020 and Beyond	*51.82*	*34.00*
Nanotechnology Knowledge Infrastructure	*22.67*	*-*
Nanotechnology for Sensors	*11.59*	*8.50*
Water Sustainability through Nanotechnology	*12.76*	*13.00*
Nanotechnology-Inspired Grand Challenge for Future Computing	*11.98*	*12.92*
2. Foundational Research	271.37	258.44
3. Nanotechnology-Enabled Applications, Devices, and Systems	57.71	50.75
4. Research Infrastructure and Instrumentation	27.91	33.40
5. Environment, Health, and Safety	12.81	10.52
Total	**$520.72**	**$453.53**