NATIONAL NANOTECHNOLOGY INITIATIVE (NNI)

National Nanotechnology Initiative (NNI) Funding[1]
(Dollars in Millions)

	FY 2023 Base Plan	FY 2024 (TBD)	FY 2025 Request
BIO	$39.95	-	$39.95
CISE	14.05	-	14.05
EDU	2.50	-	2.50
ENG	190.95	-	235.00
MPS	126.00	-	128.50
SBE	0.40	-	0.40
TIP	7.66	-	10.25
OISE	0.10	-	0.10
Total	**$381.61**	**-**	**$430.75**

[1] Funding displayed may have overlap with other topics and programs.

Overview

As indicated in the National Academies of Sciences, Engineering, and Medicine (NASEM) report *A Quadrennial Review of the National Nanotechnology Initiative* (2020),[1] "agencies should align the efforts of the NNI to deliver responsible and sustainable nanotechnology-based solutions that address the federal research and development priorities, which currently include security, artificial intelligence, quantum information sciences, manufacturing, bio-based materials, water, climate change, space travel, exploration, inhabitation, energy, medical innovations, and food and agriculture. [...] The NNI is widely viewed nationally and globally as a highly successful cross-disciplinary and interagency coordination effort — arguably the best modern example of such an effort in the United States." This document serves as the annual report for the NNI called for under the provisions of the 21st Century Nanotechnology Research and Development Act (15 USC §7501).

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 new directions in science, engineering, and technology with potentially profound implications for society. An increasing focus will be on using nanotechnology as a foundation and synergy with other emerging technologies, as well as for developing a sustainable society, mitigating climate change, and supporting foundational concepts for new vaccine development. NSF contributes to the NNI goals, and five Program Component Areas (PCAs) outlined in the 2021 NNI Strategic Plan.[2] Funding by PCA is shown at the end of this discussion.

[1] www.nationalacademies.org/our-work/quadrennial-review-of-the-national-nanotechnology-initiative
[2] www.nano.gov/2021strategicplan

Goals

The shared vision of NNI agencies is a future in which the ability to understand and control matter at the nanoscale leads to ongoing revolutions in technology and industry that benefit society. NNI agencies collaborate to achieve five strategic goals:

- Ensure that the United States remains a world leader in nanotechnology research and development.
- Promote commercialization of nanotechnology R&D.
- Provide the infrastructure to sustainably support nanotechnology research, development, and deployment.
- Engage the public and expand the nanotechnology workforce.
- Ensure the responsible development of nanotechnology.

FY 2025 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 through 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 2025.

Overall, NSF's total NNI funding in the FY 2025 Request is $430.75 million. Several new directions planned for FY 2025 include research connected to clean energy and mitigation of climate change, advanced nanomanufacturing, AI and quantum systems, the bioeconomy, sustainability, advanced wireless, and quantum biology, as well as longer-term aspects of pandemic preparedness. Nanotechnology research will contribute to and synergize with NSF's research supporting emerging technologies such as advanced semiconductors and quantum internet technologies. NSF sponsors an annual NSE grantee conference to assess progress in nanotechnology and facilitate identification of new research directions.[3]

In FY 2025, NSF support will expand convergence research and education activities in confluence with other priority areas. NSF will strengthen participation in innovation and translational programs such as Grant Opportunities for Academic Liaison with Industry (GOALI), Industry-University Cooperative Research Centers (IUCRC), the NSF Convergence Accelerator, NSF Regional Innovation Engines, and various translational programs led by the TIP directorate such as the Lab-to-Market Platform.

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*,[4] which provides a vision of the field in 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*[5] evaluating the convergence of nanotechnology with other emerging areas by 2030. Other

[3] www.nsf.gov/crssprgm/nano/ and www.nseresearch.org/2023/
[4] www.nsf.gov/crssprgm/nano/ and http://scienceus.org/wtec/docs/nano2.pdf
[5] www.nsf.gov/crssprgm/nano/ and http://scienceus.org/wtec/docs/nbic2.pdf

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.[6,7,8]

Investments by Program Component Area

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.[9] NSF supports funding in all five PCAs.

NNI Funding by Program Component Area[1]
(Dollars in Millions)

	FY 2023 Base Plan	FY 2024 (TBD)	FY 2025 Request
1. Foundational Research	$242.35	-	$258.38
2. Nanotechnology-Enabled Applications, Devices, & Systems	82.89	-	113.06
3. Research Infrastructure and Instrumentation	22.96	-	23.70
4. Education and Workforce Development	19.00	-	20.50
5. Responsible Development	14.41	-	15.11
Total	**$381.61**	**-**	**$430.75**

[1] Funding displayed may have overlap with other topics and programs.

PCA 1: Foundational Research

The FY 2025 Request includes $258.38 million to support 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 support for research 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; quantum biology for understanding natural phenomena and interfaces; water nanofiltration systems; and research directed at identifying and quantifying the broad implications of nanotechnology for society, including social, economic, ethical, and legal implications. It includes foundational research on climate change understanding and mitigation (contributing about 10 percent of PCA 1 to the nanotechnology challenge nano4EARTH),[10] Predictive Intelligence for Pandemic Prevention, and nano-Ethical, Legal and Societal Implications (ELSI). Most of the research is sponsored in individual and small group research across NSF directorates. A subset of Engineering Research Centers (ERC), Designing Materials to Revolutionize and Engineer our Future (DMREF), Science and Technology Centers (STCs), Centers for Chemical Innovation (CCIs) and other center programs support various aspects of nanoscale science and engineering. About 60 percent of the Materials Research Science and Engineering Centers (MRSECs) pursue NSE-related fundamental research.

[6] www.nsf.gov/crssprgm/nano/
[7] www.src.org/nri/energy-efficient-computing-workshop.pdf
[8] www.semiconductors.org/issues/research/research/
[9] www.nano.gov/about-nni/what/vision-goals
[10] www.nano.gov/nano4EARTH

NSF has invested in understanding the nanoscale machines that make up the cell nucleus and control cell function through its programs in Understanding the Rules of Life, the Physics Frontiers Center program, and core programs in Molecular and Cellular Biosciences (Genetic Mechanisms), Materials Research, as well as Chemistry (Chemistry of Living Processes). In FY 2025, NSF will continue its efforts in nanobiotechnology associated with synthetic biology and synthetic cells through core programs in BIO - Molecular and Cellular Biosciences (MCB), ENG - Chemical, Bioengineering, Environmental, and Transportation Systems (CBET), and CISE - Computing and Communication Foundations (CCF).

This PCA includes foundational research supporting several thematic areas:

- *Sustainable Nanomanufacturing:* Investments support foundational concepts for new nanomanufacturing methods at the confluence with digitization, biotechnology, AI, and cognitive sciences. Research in synthetic cells will lead to scalable and reproducible cell and organ production for biomanufacturing and biomedicine applications. Another new direction is manufacturing of quantum systems, nanomachines and nano biostructures. Methods for nanomanufacturing design are in synergy with the Materials Genome Initiative.
- *Nanoelectronics and Semiconductors:* Research 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. NSF will continue related investments in neuromorphic engineering, quantum systems and advanced wireless technology. Programs in CISE support these efforts.
- *Nanotechnology for Sensors and Sensors for Nanotechnology*: Research is aimed at the use of nanoscale principles and 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. It supports materials and technologies that enable new sensing of biological, chemical, and nanoscale materials. Programs on biosensing and biophotonics in CBET support this effort.
- *Nanotechnology-Inspired for Future Computing*: Research is related to "Brain-like Computing" and "Intelligent Cognitive Assistants" areas. An example of an active center is the STC on Integrated Quantum Materials at Harvard University and the MRSEC on Quantum and Spin Phenomena in Nanomagnetic Structures at the University of Nebraska, Lincoln. DNA computing is another emerging area which uses DNA, biochemistry, and molecular biology to perform algorithmic operations. Programs in CISE support these efforts.

<u>PCA 2: Nanotechnology-Enabled Applications, Devices, and Systems</u>

The FY 2025 Request includes $113.06 million for research that applies the principles of nanoscale science and engineering to create novel devices and systems, to achieve improved performance or new functionality, including metrology, scale up, manufacturing technology, large-scale performance, and nanoscale reference materials and standards. Core programs in the ENG, MPS, and CISE directorates support development of new principles, design methods, and constructive solutions for nanomaterials and nanodevices. A special focus is on smart, autonomous nanoscale-based devices and systems. PCA 2 includes applications-, device-, or systems-focused research related to Sustainable Nanomanufacturing, Nanoelectronics (semiconductors), and Nanotechnology for Sensors and Sensors for Nanotechnology. The Future Manufacturing (FM) and the Future of Semiconductors (FuSe) programs will continue in FY 2025. Future Manufacturing supports fundamental research and education of a future workforce to overcome scientific, technological, educational, economic, and social barriers to enable new manufacturing capabilities that do not exist today. FuSe supports holistic, co-design approaches to research and education in partnership with industry in order to

enable rapid progress in new semiconductor technologies. Support for climate change mitigation contributes about 5% of PCA 2 to the nanotechnology challenge nano4EARTH. Besides core nanoscience-related programs on water filtration and applications, the Nanosystems ERC for Nanotechnology Enabled Water Treatment Systems (NEWT), led by Rice University and funded between 2015 and 2024, aims to develop 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. Other ERCs do research in portable nanosensors, new nanomanufacturing processes, and new nano-electronic materials. IUCRCs focus on solar energy conversion, metrology, novel catalysts and bioplastics, novel high voltage/temperature materials and structures, and other applications.

PCA 3: Research Infrastructure and Instrumentation

The FY 2025 Request includes $23.70 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 workforce 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.

NSF has funded awards totaling about $16.0 million per year for the National Nanotechnology Coordinated Infrastructure (NNCI) sites for FY 2015–2024. Other STCs, ERCs, CCIs, and MRSECs have a focus on supporting the NNI, including the Center for Cellular Construction at the University of California-San Francisco (annual award since 2016 of approximately $5 million per year), two Nanosystems ERCs, one each on nanobiotechnology and cell technology, and a CCI at University of Wisconsin (annual award of $4.0 million per year) which investigates the fundamental molecular mechanisms by which nanoparticles interact with biological systems. The funding also includes workforce development activities at these centers and sites. NSF will increase coordinated research on its Mid-scale Research Infrastructure priority area. The Major Research Instrumentation (MRI) program[11] serves to increase access to multi-user scientific and engineering instrumentation, including instrumentation needed for NNI activities, for research and research training in the Nation's institutions of higher education and not-for-profit scientific/engineering research organizations.

PCA 4. Education and Workforce Development

In FY 2025, NSF will fund education and workforce development activities in all areas of nanoscale science and engineering, including engaging the public, at $20.50 million. Typical activities supported by EDU divisions, ENG's Division of Engineering Education and Centers, and other divisions are fellowships, single investigator awards, and centers.

The NSF INTERN program[12] supports about 75 NSE-related internships for students in industry and government labs. Illustrations of projects at the undergraduate and graduate levels are "Supporting Micro and Nano Technicians through Hybrid Teaching Methods,"[13] the Nanotechnology Applications and Career Knowledge (NACK) Resource Center,[14] the Micro Nano Technology Education Center (MNT-

[11] www.nsf.gov/funding/pgm_summ.jsp?pims_id=5260
[12] www.nsf.gov/INTERN
[13] Award DUE-2100402 (https://nsf.gov/awardsearch/showAward?AWD_ID=2100402)
[14] Award DUE-2000725 (https://nsf.gov/awardsearch/showAward?AWD_ID=2000725)

EC),[15] and "Nano-Makerspace to Make and Explore in the World of the Small."[16] The Boston Museum of Science hosts a nationwide NSE communication competition for students.[17]

PCA 5. Responsible Development

In FY 2025, NSF will continue its funding for Environment, Health, and Safety (EHS), ELSI, and diversity, equity, inclusion, and access, as well as nanotechnology research integrity, safety, and reproducibility at $15.11 million. Requests for research are primarily directed at understanding nano-bio phenomena and processes, as well as environment, health, societal, and safety implications and methods for reducing the respective risks of nanotechnology development. ENG's nano EHS program has changed to *Nanoscale Interactions*. MPS supports the CCI: Center for Sustainable Nanotechnology at the University of Wisconsin.[18] Support will be increased for diversity, equity, inclusion and access for underrepresented groups, women and persons with disabilities interested in nanoscale science and engineering, for various knowledge and technology fields to be explored in conjunction with nanotechnology, and for broad geographical representation across the U.S.

Coordination with Other Agencies

NSF's NNI activities are coordinated with 20 other departments, of which several have multiple participating agencies, through the National Science and Technology Council subcommittee on Nanoscale Science, Engineering, and Technology (NSTC/NSET). These agencies also partner with NSF to sponsor joint funding opportunities and workshops on nanotechnology research directions and send representatives to participate in grantees conferences. Some specific coordination efforts are:

- Nano4EARTH partnerships with all NNI agencies, including EPA, FDA, and DOE.
- 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).
- Nanoelectronics and semiconductors—NSF, NIST, Department of Defense (DOD), DOE, Intelligence Community (IC)/Director of National Intelligence (DNI), and NASA.
- NSF collaborates with other 20 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.
- Nano-EHS collaboration in the Nanotechnology Environment, Health, and Safety WG.
- NSF INTERN supports NSE-related internships at DOD/AFRL, DOE, and National Institute of Justice.
- Organization for Economic Cooperation and Development (OECD) Working Group on Bio, Nano, and other Converging Technologies.

[15] Award DUE-2000281 (https://nsf.gov/awardsearch/showAward?AWD_ID=2000281)
[16] Award DUE-1723511 (https://nsf.gov/awardsearch/showAward?AWD_ID=1723511)
[17] www.mos.org/quantum-matters-competition
[18] https://susnano.wisc.edu/