

NATIONAL NANOTECHNOLOGY INITIATIVE (NNI)**Total Funding for NNI**

(Dollars in Millions)

	FY 2022 Actual	FY 2023 Esimate	FY 2024 Request
BIO	\$39.95	\$39.95	\$39.95
CISE	15.62	14.05	14.05
EDU	10.85	2.50	2.50
ENG	267.13	191.25	231.75
MPS	206.17	126.00	126.00
SBE	0.40	0.40	0.40
OISE	0.10	0.10	0.10
TIP	4.90	10.05	13.54
Total	\$545.12	\$384.30	\$428.29

Overview

As indicated in the National Academies of Sciences, Engineering, and Medicine report *A Quadrennial Review of the National Nanotechnology Initiative (2020, <https://www.nationalacademies.org/our-work/quadrennial-review-of-the-national-nanotechnology-initiative>)*, the agency “should align the efforts of the NNI to deliver responsible and sustainable nanotechnology-based solutions that address the federal research and development (R&D) 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. 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 US.” This document serves as the annual report for the National Nanotechnology Initiative 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 increased focus will be on using nanotechnology as a foundation and synergy with other emerging technologies, as well as for 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 current draft of the 2026 NNI Strategic Plan.¹ Funding by PCA is shown at the end of this discussion.

NNI 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

¹ www.nano.gov/2021strategicplan

deployment

- Engage the Public and Expand the Nanotechnology Workforce
- Ensure the responsible development of nanotechnology

FY 2024 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 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 2024. Overall, NSF's total NNI funding in the FY 2024 Request is \$428.29 million. Several new directions planned for FY 2024 include research connected to mitigation of climate change, advanced nanomanufacturing, AI and quantum systems, the bioeconomy, sustainability, advanced wireless, and quantum biology, as well as to longer-term aspects of pandemic preparedness. Nanotechnology research will contribute and synergize with NSF's Big Ideas, particularly with URoL, FW-HTF, HDR, and GCR, as well as with research supporting emerging technologies such as advanced semiconductors. NSF sponsors an annual NSE grantee conference to assess the progress in nanotechnology and facilitate identification of new research directions.²

In FY 2024, NSF support will increasingly focus on convergence research and education activities in confluence with other priority areas. NSF will strengthen partnerships with translational programs such as through the new TIP programs including Convergence Accelerators and ENGINES; Grant Opportunities for Academic Liaison with Industry (GOALI); and Industry-University Cooperative Research Centers (IUCRC); as well as translation through the NSF Innovation Corps (I-Corps™), Partnerships for Innovation (PFI), and Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs.

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}

² 2021 Nanoscale Science and Engineering Grantees Conference: www.nsf.gov/crssprgm/nano/ and www.nseresearch.org/2022/

³ NSF/WTEC 2010, Springer, available on www.nsf.gov/crssprgm/nano/ and <http://scienceus.org/wtec/docs/nano2.pdf>

⁴ NSF/WTEC 2013, Springer, available on www.nsf.gov/crssprgm/nano/ and <http://scienceus.org/wtec/docs/nbic2.pdf>

⁵ www.nsf.gov/crssprgm/nano/

⁶ www.src.org/nri/energy-efficient-computing-workshop.pdf

⁷ www.semiconductors.org/issues/research/research/

National Academies of Sciences, Engineering, and Medicine (the National Academies) report to Congress in 2020 provides guidance on research priorities, partnerships, and future growth, including: "Finding 1.2 - The National Quantum Initiative (NQI) is, in large part, an important outgrowth of the National Nanotechnology Initiative (NNI)," "Impacts of NNI to date: Impressive, tangible outcomes that have emerged from these coordination efforts, including the recent formation of the NQI."^{8,9}

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.¹⁰ NSF supports funding in all five PCAs.

	FY 2022 Actual	FY 2023 Estimate	FY 2024 Request
1. Foundational Research	\$329.76	\$232.90	\$259.00
2. Nanotechnology-Enabled Applications, Devices, and Systems	139.51	99.00	110.29
3. Research Infrastructure and Instrumentation	27.68	18.00	21.00
4. Education and Workforce Development	30.85	22.00	24.00
5. Responsible Development	17.33	12.40	14.00
Total	\$545.12	\$384.30	\$428.29

Note: 10% of PCA1 and 5% of PCA2 in FY 2024 will be dedicated to the National Nanotechnology Challenge nano4EARTH

PCA 1: Foundational Research

The first PCA will be funded at a total of \$259.00 million in FY 2024. It includes funding 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; 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% of PCA 1 to the nanotechnology challenge nano4EARTH (<https://www.nano.gov/nano4EARTH>)), 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), 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.

NSF has invested in understanding the nanoscale machines that make up the nucleus of a cell 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) as

⁸ www.nationalacademies.org/our-work/quadrennial-review-of-the-national-nanotechnology-initiative

⁹ www.nap.edu/resource/25729/A%20Quadrennial%20Review%20NNI%20Presentation%20slides%20v15.pdf

¹⁰ www.nano.gov/about-nni/what/vision-goals

well as Chemistry (Chemistry of Living Processes). In FY 2024, NSF will also continue its efforts in nanobiotechnology associated with synthetic biology and synthetic cells through core programs in BIO - Molecular and Cellular Biosciences (MCB) and ENG - Chemical, Bioengineering, Environmental, and Transportation Systems (CBET).

This PCA includes foundational research supporting the: Sustainable Nanomanufacturing, Nanoelectronics including semiconductors, Nanotechnology for Sensors, and Sensors for Nanotechnology, as well as research on the Nanotechnology-Inspired for Future Computing.

- *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. Included in this emphasis area is *Designing Synthetic Cells beyond the bounds of Evolution*, that will have enabled novel nanomanufacturing applications and *Reproducible Cells and Organoids via Directed-Differentiation Encoding (RECODE)* that will lead to scalable and reproducible cell and organ production for biomanufacturing and biomedicine applications.
- *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 quantum systems and advanced wireless technology.
- *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.

PCA 2: Nanotechnology-Enabled Applications, Devices, and Systems

The FY 2024 Request includes \$110.29 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, 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 Sustainable Nanomanufacturing, Nanoelectronics (semiconductors), Nanotechnology for Sensors and Sensors for Nanotechnology. The Future Manufacturing solicitation announced in 2020 will continue into 2023 and 2024.¹¹ The goal of Future Manufacturing is to support fundamental research and education of a future workforce to overcome scientific, technological, educational, economic, and social barriers to enable new

¹¹ <https://beta.nsf.gov/funding/opportunities/national-science-foundation-future-semiconductor>

manufacturing capabilities that do not exist today. Support for climate change mitigation (contributing about 5% of PCA 2 to the nanotechnology challenge nano4EARTH (<https://www.nano.gov/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 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. Other ERCs perform research in portable nanosensors, new nanomanufacturing processes, and new nano-electronic materials. IUCRCs focus on solar energy conversion, metrology, novel catalysts and bioplastics, and novel high voltage/temperature materials and structures.

PCA 3: Research Infrastructure and Instrumentation

The FY 2024 Request includes \$21.00 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, nano-HUB nodes, 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 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) Program¹² 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 2024, NSF will fund education and workforce development activities in all areas of nanoscale science and engineering, including engaging the public, at \$24.00 million. Typical activities supported by the Directorate for STEM Education, ENG's Division of Engineering Education and Centers, and other divisions are fellowships, single investigator awards, and centers.

The NSF INTERN program¹³ 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,"¹⁴ the Nanotechnology Applications

¹² www.nsf.gov/funding/pgm_summ.jsp?pims_id=5260

¹³ www.nsf.gov/INTERN

¹⁴ Award DUE-2100402 (https://nsf.gov/awardsearch/showAward?AWD_ID=2100402)

and Career Knowledge (NACK) Resource Center,¹⁵ the Micro Nano Technology Education Center (MNT-EC),¹⁶ and “Nano-Makerspace to Make and Explore in the World of the Small”¹⁷. The Boston Museum of Science hosts a nationwide NSE communication competition for undergraduate and graduate students.¹⁸

PCA 5. Responsible Development

In FY 2024, NSF will continue its funding for Environment, Health, and Safety (EHS), ELSI, and diversity/equity/inclusion/access, as well as nanotechnology research integrity, safety, and reproducibility at \$14.00 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.¹⁹ Support will be increased for diversity and equity by 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 in all 50 states.

Coordination with Other Agencies

NSF’s NNI program is coordinated with 20 other departments, of which several with 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 activities 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.
- INTERN program supports NSE-related internships at DOD/AFRL.
- OECD (Working Group on Bio, Nano, and other Converging Technologies)

¹⁵ Award DUE-2000725 (https://nsf.gov/awardsearch/showAward?AWD_ID=2000725)

¹⁶ Award DUE-2000281 (https://nsf.gov/awardsearch/showAward?AWD_ID=2000281)

¹⁷ Award DUE-1723511 (https://nsf.gov/awardsearch/showAward?AWD_ID=1723511)

¹⁸ www.mos.org/quantum-matters-competition

¹⁹ <https://susnano.wisc.edu/>