THE WHITE HOUSE

NATIONAL NANOTECHNOLOGY INITIATIVE SUPPLEMENT TO THE PRESIDENT'S 2026 BUDGET

April 2026

About this Document

This document is a product of the Committee on Technology, Subcommittee on Nanoscale Science, Engineering, and Technology of the National Science and Technology Council. It is a supplement to the President's 2026 Budget request submitted to Congress on May 2, 2025, and 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 §7501–7509). The report also addresses the requirement for Department of War reporting on its nanotechnology investments (10 USC Chapter 303).

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Small Business Administration (SBA)

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† Denotes an independent commission that is represented on NSET but is non-voting.

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Abbreviations and Acronyms

2D	two-dimensional
3D	three-dimensional
AFOSR	Air Force Office of Scientific Research
AFRI	Agriculture and Food Research Initiative (USDA)
AFRL	Air Force Research Laboratory
AI	artificial intelligence
ANL	Argonne National Laboratory
AREA	Academic Research Enhancement Award (NIH)
ARL	Army Research Laboratory
ARO	Army Research Office
ARS	Agricultural Research Service (USDA)
ATSDR	Agency for Toxic Substances and Disease Registry (HHS)
BARDA	Biomedical Advanced Research and Development Authority (HHS)
CBER	Center for Biologics Evaluation and Research (FDA)
CCIs	Centers for Chemical Innovation (NSF)
CDER	Center for Drug Evaluation and Research (FDA)
Chem/Bio	Chemical and Biological Defense (DOW program)
CNST	Center for Nanoscale Science and Technology (NIST)
CNT	carbon nanotube
CPSC	Consumer Product Safety Commission
CWMD	Countering Weapons of Mass Destruction Office (DHS)
DARPA	Defense Advanced Research Projects Agency
DHS	Department of Homeland Security
DOC	dental, oral, and craniofacial
DOC	Department of Commerce
DOE	Department of Energy
DOJ	Department of Justice
DOT	Department of Transportation
DOW	Department of War
DTRA	Defense Threat Reduction Agency
EPA	Environmental Protection Agency
ERCs	Engineering Research Centers (NSF)
FDA	Food and Drug Administration (HHS)
FHWA	Federal Highway Administration (DOT)
FS	Forest Service (USDA)
HFP	Human Foods Program (FDA)
HHS	Department of Health and Human Services
ISO	International Organization for Standardization
IUCRC	Industry-University Cooperative Research Centers (NSF)
LNP	lipid nanoparticle
MIP	Materials Innovation Platform (NSF)
MNPs	micro-/nanoplastics
MOF	metal organic framework
MRI	magnetic resonance imaging
MRSECs	Materials Research Science and Engineering Centers (NSF)
NanoCore	Nanotechnology Core Facility (FDA/NCTR)
nanoEHS	nanotechnology-related environmental, health, and safety

NASA	National Aeronautics and Space Administration
NCEH	National Center for Environmental Health (HHS)
NCI	National Cancer Institute (NIH)
NCL	Nanotechnology Characterization Laboratory (NIH/NCI)
NCTR	National Center for Toxicological Research (FDA)
NEHI	Nanotechnology Environmental and Health Implications (NNI working group)
NEI	National Eye Institute
NHGRI	National Human Genome Research Institute (NIH)
NHLBI	National Heart, Lung, and Blood Institute (NIH)
NIAID	National Institute of Allergy and Infectious Diseases (NIH)
NIBIB	National Institute of Biomedical Imaging and Bioengineering (NIH)
NIDCR	National Institute of Dental and Craniofacial Research (NIH)
NIEHS	National Institute of Environmental Health Sciences (NIH)
NIFA	National Institute of Food and Agriculture (USDA)
NIH	National Institutes of Health (HHS)
NIJ	National Institute of Justice (DOJ)
NIOSH	National Institute for Occupational Safety and Health (HHS)
NIST	National Institute of Standards and Technology (DOC)
NNCI	National Nanotechnology Coordinated Infrastructure (NSF)
NNCO	National Nanotechnology Coordination Office
NNI	National Nanotechnology Initiative
NRL	Naval Research Laboratory
NSE	nanoscale science and engineering
NSET	Nanoscale Science, Engineering, and Technology (Subcommittee, NSTC)
NSF	U.S. National Science Foundation
NSRCs	Nanoscale Science Research Centers (DOE)
NSTC	National Science and Technology Council
OMB	Office of Management and Budget
ONR	Office of Naval Research
ORNL	Oak Ridge National Laboratory
OSTP	Office of Science and Technology Policy
PCA	Program Component Area (NNI budget category)
PFAS	per- and polyfluoroalkyl substances
QIS	quantum information science
R&D	research and development
SBIR	Small Business Innovation Research (program)
STC	Science and Technology Center (NSF)
STEM	science, technology, engineering, and mathematics
STTR	Small Business Technology Transfer Research (program)
USDA	(U.S.) Department of Agriculture

Executive Summary

President Trump's 2026 Budget requests $1.45 billion for the National Nanotechnology Initiative (NNI), an integrated multiagency research and development (R&D) program authorized under the 21st Century Nanotechnology Research and Development Act. As called for in that Act, this report provides the program budget for 2024 and 2025, as well as the requested budget for 2026. As required, it also provides a breakout of agency plans and spending by NNI Program Component Area—foundational research; applications, devices, and systems; research infrastructure and instrumentation; education and workforce development, and responsible development of nanotechnology. The report includes selected examples of progress towards the NNI's goals, information on how Federal agencies are using the Small Business Innovation Research and Small Business Technology Transfer programs to promote commercialization and deployment of nanotechnology for the betterment of the Nation, and a discussion of the latest external evaluation of the NNI by the National Academies of Science, Engineering, and Medicine.

As this report demonstrates, nanotechnology R&D coordinated under the auspices of the NNI is fundamental to advancing the Trump Administration's R&D priority of ensuring unrivalled American leadership in critical and emerging technologies. Progress in artificial intelligence, quantum information science, semiconductors and microelectronics, advanced communications networks, future computing technologies, and advanced manufacturing all depend on nanoscale science and engineering. Nanotechnology R&D also underpins efforts to unleash American energy dominance, strengthen American security, safeguard American health and biotechnology, and assure America's continued space dominance.

What is nanotechnology?

Nanotechnology is the understanding and control of matter at the nanoscale—at dimensions between approximately 1 and 100 nanometers—where unique phenomena enable novel applications. A nanometer is one-billionth of a meter. For reference, a sheet of paper is about 100,000 nanometers thick. Matter can exhibit unusual physical, chemical, and biological properties at the nanoscale, differing in important ways from the properties of bulk materials, single atoms, and molecules. Some nanostructured materials are stronger or have different magnetic properties compared to other forms or sizes of the same material. Others are better at conducting heat or electricity. Nanomaterials may become more chemically reactive, reflect light better, or change color as their size or structure is altered.

Nanotechnology serves as the foundation for key industries of the future such as artificial intelligence, quantum information science, and advanced manufacturing. Nanotechnology innovations are ensuring continued U.S. leadership in the semiconductor and strategic computing industries, and are advancing many other national priorities, including space exploration, energy, advanced communications (5G/6G), healthcare, agriculture, aviation, and national security.

Examples of nanotechnology innovations are illustrated below: (a) flexible electronics for smart bandages, real-time health monitoring, and therapeutics; (b) specialized and energy-efficient hardware for artificial intelligence; (c) nanowire photon detectors for high-speed quantum communication; (d) nanomaterials for enhanced oil production and more efficient refining; (e) materials and devices for water testing and purification; (f) radiation-resistant materials for nuclear fission and fusion power reactors; (g) multifunctional, lightweight, and heat-resistant materials for aerospace applications; (h) smart windows enabled by nanoscale coatings for more energy-efficient and comfortable buildings.

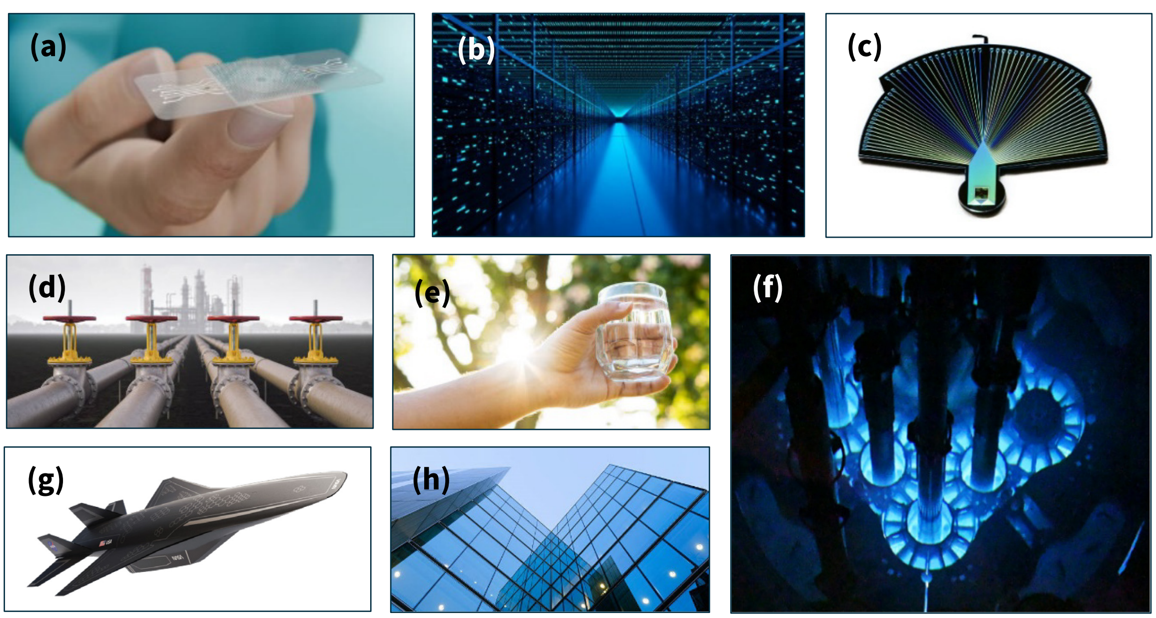

Image credits: (a) iStock, (b) iStock, (c) NASA, (d) iStock, (e) iStock, (f) DOE, (g) NASA, (h) iStock. For more information on nanotechnology benefits and applications, please visit www.nano.gov/about-nanotechnology/applications-nanotechnology.

1. Introduction

About the National Nanotechnology Initiative

The National Nanotechnology Initiative (NNI) is a U.S. government research and development (R&D) initiative involving 20 Federal departments, independent agencies, and commissions working together toward the shared vision of 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. The NNI establishes shared national goals, priorities, and strategies to expand global leadership through interagency coordination of nanotechnology R&D. This work builds on agency-specific missions and activities and enhances government efficiency by leveraging resources and avoiding duplication. It also supports an extensive nanotechnology research infrastructure (including user facilities and multidisciplinary research centers) that facilitates the work of America's scientists, engineers, and entrepreneurs in many other fields of science and technology.

The NNI advances multiple Trump Administration science and technology priorities, including artificial intelligence (AI), quantum information science (QIS), and biotechnology. For example, semiconductor technologies have long been at the nanoscale, and a broad range of information and communication technologies including high-end computing, advanced wireless (6G), and artificial intelligence, require new nanomaterials and architectures to enable enhanced performance, memory-centric computing, low power, and other novel functionalities. Furthermore, research and development in these priority areas is dependent on the NNI research infrastructure networks that provide access to fabrication and characterization facilities across the country.

NNI participating agencies support applied research, experimental development, pre-commercialization, workforce development, and standards-related efforts that build the Nation's economic competitiveness, helping create good-paying jobs across the country, including in both traditional and emerging industries. The coordination provided through the NNI has facilitated the responsible development of new technologies, streamlining their adoption for the benefit of the Nation.

The foundational nanotechnology research funded under the NNI continues to strengthen and advance America's global leadership in science and technology, and the NNI's research infrastructure provides access to state-of-the-art facilities and expertise that expand the boundaries of nanoscale science. This report highlights nanotechnology research accomplishments funded under the NNI and presents plans for future R&D activities by the participating agencies.

Under the auspices of the NNI, multiple agencies work together to leverage their respective knowledge and resources, creating a program that is greater than the sum of the individual agency activities. The NNI works with academia and the private sector to promote technology transfer and facilitate commercialization. NNI activities are coordinated by the Nanoscale Science, Engineering, and Technology (NSET) Subcommittee of the National Science and Technology Council (NSTC), with technical and administrative support from the National Nanotechnology Coordination Office (NNCO), which also conducts public outreach on behalf of the NNI and promotes education and workforce development.

External Reviews of the NNI

The National Academies of Science, Engineering, and Medicine (NASEM) released its latest review of the NNI in calendar year 2025.[1] The report focused on evaluating the NNI's research infrastructure—including people, instruments, and facilities—and on how to maximize its impact in current and emerging use cases. The report made six key recommendations: (1) NNCO should conduct a census of accessible nanotechnology infrastructure sites (instruments, staff, facilities) and display findings on a public, web-accessible map that includes university, regional, and national resources; (2) Congress should reauthorize the NNI as the "National Nanotechnology Infrastructure" and orient NNCO and agency activities toward the renewal and expansion of the infrastructure; (3) NNCO should undertake a study to determine the level of resources needed to maintain state-of-the-art nanotechnology infrastructure; (4) Federal agencies that support nanotechnology infrastructure should prioritize investment in new capabilities that advance fabrication, materials synthesis, characterization, and data analysis to support emerging technologies; (5) agencies that fund nanotechnology infrastructure should include in their infrastructure evaluations measures of performance that capture the breadth and heterogeneity of the associated user bases; and (6) these agencies should provide dedicated travel support for infrastructure users and, where feasible, summer access for academics, researchers, and students who are not from R1 institutions. In July 2025 NASEM hosted a webinar during which members of its NNI evaluation panel summarized the report, followed by a roundtable discussion with other nanotechnology experts on how modernizing and expanding access to nanotechnology R&D infrastructure can drive U.S. innovation in critical areas.[2] These recommendations are under consideration by the NNI.

Outline of this Report

Chapter 2 of this report is an overview of the budgets for nanotechnology R&D for 2024 (actual), 2025 (estimated), and 2026 (requested),[3] as well as funding amounts and examples of nanotechnology R&D topics funded under the Small Business Innovation Research (SBIR) and Small Business Technology Transfer Research (STTR) programs. Chapter 3 presents examples of individual agency and collective progress toward the NNI goals and highlights of agency plans and priorities by Program Component Area (PCA).

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1 nap.nationalacademies.org/catalog/29063/quadrennial-review-of-the-national-nanotechnology-initiative-2025-securing-us

2 www.nationalacademies.org/event/45318_07-2025_nanotechnology-r-d-infrastructure-then-and-now

3 References to years in this report are to fiscal years unless otherwise noted.

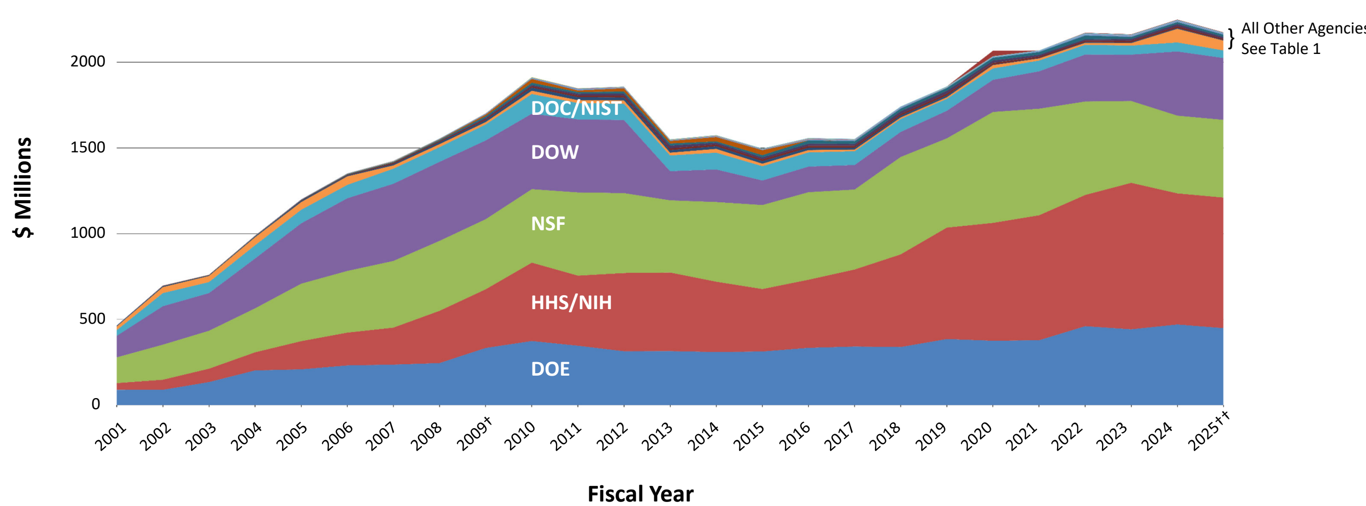
2. NNI Budget

Budget Summary

The President's 2026 Budget requests $1.45 billion for the NNI, with key investments in foundational research that will fuel new discoveries and in application-driven R&D to advance technologies of the future and address national priorities. Cumulative NNI funding since its inception in 2001 totals nearly $47 billion (including the 2026 request); Figure 1 shows the funding trends over time. Table 1 shows total NNI funding by agency for fiscal years 2024 through 2026. NNI investments support research to understand matter at the nanoscale and to translate this knowledge into technological breakthroughs that benefit all Americans. The NNI investments in 2024 and 2025 and those proposed for 2026 reflect support for fundamental research in nanoscience; programs to advance applications, devices, and systems; and support for the responsible development of nanotechnology. NNI agencies also support significant investments in research infrastructure, developing new research tools, and making these tools available through user facilities, as well as science, technology, engineering, and mathematics (STEM) education to prepare the workforce of the future.

The NNI budget represents the sum of nanotechnology-related investments allocated by each participating agency (the "NNI crosscut"). Each agency determines its budget for programs supporting nanotechnology R&D in coordination with the Office of Management and Budget (OMB), OSTP, and Congress. NNI agencies collaborate closely—facilitated through the NSET Subcommittee, its Nanotechnology Environmental and Health Implications (NEHI) Working Group, informal communities of interest, and the NNCO—to create an integrated R&D program that leverages and amplifies resources to advance NNI goals and meet individual agency mission needs and objectives.

Figure 1. NNI Funding by Agency, 2001–2025.*



* Graph does not include Biomedical Advanced Research and Development Authority (BARDA) supplemental investments: $2.9 billion (2020), $1.7 billion (2021), and $350 million (2022).

† 2009 figures do not include American Recovery and Reinvestment Act funds for DOE, NSF, NIH, and NIST.

†† 2025 numbers are based on enacted levels.

Table 1: NNI Budget, by Agency, 2024–2026 (dollars in millions)			
Agency	2024 Actual	2025 Estimated*	2026 Proposed
CPSC	0.05	0.0	0.0
DHS/CWMD	0.5	0.0	0.0
DOC/NIST	52.8	44.6	38.3
DOE****	469.9	448.2	368.0
DOJ/NIJ	2.0	1.8	1.8
DOT/FHWA	0.1	0.1	0.1
DOW***	374.2	360.7	394.2
EPA	4.3	2.8	2.8
HHS (total)	789.8	780.8	470.7
BARDA	2.1	0.0	0.0
FDA	12.4	11.1	11.7
NIH	764.9	761.7	459.0
NIOSH	10.5	8.0	0.0
NASA******	80.1	57.0	27.1
NSF	453.0	403.9	131.1
USDA (total)	21.6	22.6	15.0
ARS	5.0	5.0	5.0
FS	4.6	4.6	0.0
NIFA	12.0	13.0	10.0
TOTAL†	**2248.3**	**2122.4**	**1449.1**

* 2025 numbers are based on enacted levels.
** Funding levels for DOE include the combined budgets of multiple DOE offices.
*** Funding levels for DOW include the combined budgets of the Air Force, Army, Navy, Defense Advanced Research Projects Agency, Defense Threat Reduction Agency, Office of the Under Secretary of War for Research and Engineering, Coalition Warfare Program, and Joint Program Executive Office for Chemical, Biological, Radiological, and Nuclear Defense.
**** Funding levels for NASA include nanotechnology-related activities of the Science Mission Directorate, which were not reported in prior years.
† In Tables 1–5, totals may not add, due to rounding.

The President's 2026 Budget includes a request of $1.45 billion for nanotechnology R&D to support nanoscale science, engineering, and technology R&D at 10 agencies, including multiple departments/offices within several agencies such as the Department of War (DOW), the Department of Health and Human Services (HHS), the Department of Agriculture (USDA), and the Department of Energy (DOE) (see Table 1 above and the footnotes for DOW and DOE). The six Federal organizations with the largest proposed 2026 investments (representing nearly 98% of the NNI total) are:

- HHS/National Institutes of Health (NIH)—nanotechnology-based biomedical research at the intersection of life and physical sciences.
- DOW—science and engineering research advancing defense and dual-use capabilities.
- DOE—fundamental and applied research providing a basis for new and improved energy technologies, and support for nanotechnology research infrastructure.

- U.S. National Science Foundation (NSF)—fundamental research and education across all disciplines of science and engineering.
- Department of Commerce (DOC)/National Institute of Standards and Technology (NIST)—fundamental research and development of measurement and fabrication tools, analytical methodologies, metrology, and standards for nanotechnology.
- National Aeronautics and Space Administration (NASA)—applied and fundamental research for aeronautics, space-based science, and human exploration of the Moon and Mars.

Breakout of Funding by PCA

Tables 2–4 show the funding for 2024–2026 by agency and Program Component Area. The PCAs are aligned with the NNI goals. PCA definitions can be found on Nano.gov.[4]

Table 2: Actual 2024 Agency Investments by Program Component Area (dollars in millions)

Agency	1. Foundational Research	2. Nanotechnology-Enabled Applications,	3. Research Infrastructure and Instrumentation	4. Education and Workforce Development	5. Responsible Development	NNI Total
CPSC	0.0	0.0	0.0	0.0	0.05	0.05
DHS/CWMD	0.0	0.5	0.0	0.0	0.0	0.5
DOC/NIST	14.5	8.1	27.4	0.0	2.8	52.8
DOE	238.3	67.5	164.1	0.0	0.0	469.9
DOJ/NIJ	0.5	1.5	0.0	0.0	0.0	2.0
DOT/FHWA	0.0	0.1	0.0	0.0	0.0	0.1
DOW	298.3	64.4	10.4	0.0	1.1	374.2
EPA	0.0	0.0	0.0	0.0	4.3	4.3
HHS (total)	148.2	587.6	18.1	4.7	31.2	789.8
BARDA	0.0	2.1	0.0	0.0	0.0	2.1
FDA	5.4	5.3	0.0	0.0	1.7	12.4
NIH	142.8	580.2	18.1	4.7	19.1	764.9
NIOSH	0.0	0.0	0.0	0.0	10.5	10.5
NASA	59.7	20.4	0.0	0.0	0.0	80.1
NSF*	295.2	92.5	30.9	20.9	13.5	453.0
USDA (total)	5.0	14.6	0.0	1.0	1.0	21.6
ARS	0.0	5.0	0.0	0.0	0.0	5.0
FS	0.0	4.6	0.0	0.0	0.0	4.6
NIFA	5.0	5.0	0.0	1.0	1.0	12.0
TOTAL	**1059.6**	**857.3**	**250.9**	**26.6**	**53.9**	**2248.3**

* NSF total includes ~$0.3 million in supplemental 2024 funding (PCA 1).

4 www.nano.gov/pcadefinitions

Table 3: Estimated 2025 Agency Investments by Program Component Area (dollars in millions)*						
Agency	PCA 1	PCA 2	PCA 3	PCA 4	PCA 5	Total
DOC/NIST	13.0	7.0	22.0	0.0	2.6	44.6
DOE	230.8	47.2	170.2	0.0	0.0	448.2
DOJ/NIJ	0.5	1.2	0.0	0.1	0.0	1.8
DOT/FHWA	0.0	0.1	0.0	0.0	0.0	0.1
DOW	285.3	60.2	14.8	0.0	0.5	360.7
EPA	0.0	0.0	0.0	0.0	2.8	2.8
HHS (total)	146.6	582.7	18.1	4.7	28.7	780.8
FDA	4.0	5.5	0.0	0.0	1.7	11.1
NIH	142.6	577.2	18.1	4.7	19.1	761.7
NIOSH	0.0	0.0	0.0	0.0	8.0	8.0
NASA	45.2	11.8	0.0	0.0	0.0	57.0
NSF	257.4	88.7	25.4	19.0	13.5	403.9
USDA (total)	6.0	14.6	0.0	1.0	1.0	22.6
ARS	0.0	5.0	0.0	0.0	0.0	5.0
FS	0.0	4.6	0.0	0.0	0.0	4.6
NIFA	6.0	5.0	0.0	1.0	1.0	13.0
TOTAL	**984.7**	**813.5**	**250.4**	**24.8**	**49.1**	**2122.4**

Table 4: Proposed 2026 Agency Investments by Program Component Area (dollars in millions)						
Agency	PCA 1	PCA 2	PCA 3	PCA 4	PCA 5	Total
DOC/NIST	10.1	6.2	22.0	0.0	0.0	38.3
DOE	175.4	19.3	173.3	0.0	0.0	368.0
DOJ/NIJ	0.5	1.2	0.0	0.1	0.0	1.8
DOT/FHWA	0.0	0.1	0.0	0.0	0.0	0.1
DOW	338.4	54.4	1.4	0.0	0.0	394.2
EPA	0.0	0.0	0.0	0.0	2.8	2.8
HHS (total)	90.1	357.2	10.8	3.0	9.5	470.7
FDA	4.3	6.0	0	0	1.3	11.7
NIH	85.8	351.2	10.8	3.0	8.2	459.0
NASA	21.7	5.4	0.0	0.0	0.0	27.1
NSF	75.2	43.5	4.2	5.0	3.2	131.1
USDA (total)	5.0	9.0	0.0	1.0	0.0	15.0
ARS	0.0	5.0	0.0	0.0	0.0	5.0
NIFA	5.0	4.0	0.0	1.0	0.0	10.0
TOTAL	**716.5**	**496.3**	**211.8**	**9.1**	**15.5**	**1449.1**

* Headings in Tables 3 and 4 are abbreviated to PCA numbers.

As nanotechnology and its applications mature, investments by some agencies and departments that perform research to facilitate their missions have risen in recent years. Most notably, DOW's investments have more than doubled in ten years—from less than $150 million in 2016 to $394 million in the 2026 request. Nanotechnology investments at the Food and Drug Administration (FDA) are also up from figures reported previously, from just under $8 million/year[5] to between $11 million and $12 million/year for 2024–2026, in spite of an overall austere budget environment, as more nanotechnology-enabled medical products are coming to the agency for review. The percentage of total NNI investments in the "applications, devices, and systems" PCAs has risen from under 24% in 2016 to over 38% in 2024. Nanotechnology continues to contribute solutions to agency mission requirements.

However, even as nanotechnology applications emerge, it is vital to maintain the pipeline of fundamental research investments that will enable the development of future applications. The NNI request for foundational research (PCA 1) for 2026 is over 49% of the total request; there is still plenty of room for fundamental research at the nanoscale.

Many of the proposed 2026 NNI investments outlined in this report support efforts to renew U.S. leadership in the semiconductor and microelectronics industries. Foundational nanomaterials research (PCA 1) and nanoelectronic devices and systems (PCA 2) are enabling leapfrog capabilities in microelectronics to empower artificial intelligence. As called out in the National Strategy for Microelectronics Research,[6] dramatic improvements in the energy efficiency of semiconductor devices are critical for continued progress in the U.S. microelectronics industry, and this is particularly important for compute-intensive applications such as AI. Nanotechnology is key to addressing this issue, with R&D on new nanoscale hardware-based solutions. The DOE Microelectronics Science Research Centers[7] will expand investments in early-stage innovations. Existing microelectronics research infrastructure supported through the NSF-funded National Nanotechnology Coordinated Infrastructure (NNCI), the DOE Nanoscale Science Research Centers (NSRCs), and the NIST Center for Nanoscale Science and Technology (CNST) and Boulder Microfabrication Facility, as well as several DOW-supported centers (PCA 3), also provide a strong foundation for the additional microelectronics infrastructure being developed as part of CHIPS R&D efforts.[8] NSF is expanding on its existing nanoscience and engineering education programs (PCA 4) to develop semiconductor workforce and education activities funded under the CHIPS and Science Act.[9] NNCO provides staff support for the interagency group that is coordinating microelectronics and semiconductor R&D, education, and infrastructure.

SBIR and STTR Funding to Advance Nanotechnology

This section of the report includes information on use of the Small Business Innovation Research and Small Business Technology Transfer programs to support nanotechnology development, as well as examples of agency SBIR and STTR award topics that support the accelerated deployment and application of nanotechnology R&D with potential for commercialization. Table 5 shows agency funding for SBIR and STTR awards for nanotechnology R&D from 2020 through 2023. (2023 is the latest year for which nanotechnology award data researched by agencies and OMB are available.) NNI participating

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5 As reported in the NNI Supplement to the President's 2024 Budget, p. 6 (www.nano.gov/sites/default/files/pub_resource/NNI-FY24-Budget-Supplement.pdf)

6 www.whitehouse.gov/wp-content/uploads/2025/03/Amended-National-Strategy-on-Microelectronics-Research.pdf

7 www.energy.gov/science/articles/department-energy-announces-179-million-microelectronics-science-research-centers

8 See the Plans for PCA 2 section below, beginning on p. 26, for details on the new nanotechnology-related investments under the CHIPS and Science Act.

9 sam.gov/opp/1e808bc8f585427da4b560b98e32c820/view

agencies have supported just over $2.7 billion in nanotechnology SBIR and STTR awards (both Phase I and Phase II) since 2004.[10] Total nanotechnology SBIR/STTR investments reached an all-time high of over $250 million in 2022, with another $230 million invested in 2023. Even though not all agencies specifically identify nanotechnology in their SBIR/STTR solicitations, their efforts are enabling innovations in many nanotechnology-related R&D application areas. Information on progress and plans in programs other than SBIR/STTR in promoting commercialization of nanotechnology innovations is included in Chapter 3 of this report (Goal 2 and PCA 2 sections).

Table 5: 2020–2023 Agency SBIR and STTR Awards
(dollars in millions)

	2020			2021			2022			2023		
Agency	SBIR	STTR	Total	SBIR	STTR	Total	SBIR	STTR	Total	SBIR	STTR	Total
DHS	1.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DOC/NIST	1.9	0.0	1.9	1.3	0.0	1.3	3.9	0.0	3.9	12.9	0.0	12.9
DOE	26.0	3.7	29.7	27.3	8.8	36.0	44.1	13.2	57.3	32.3	8.3	40.6
DOW	51.5	17.8	69.3	45.5	23.1	68.6	85.5	23.7	109.2	41.1	12.5	53.6
EPA	0.5	0.0	0.5	0.6	0.0	0.6	0.2	0.0	0.2	0.0	0.0	0.0
HHS/NIH	42.9	5.7	48.6	41.8	6.5	48.3	38.7	7.0	45.7	48.8	8.4	57.3
NASA	6.5	2.8	9.3	9.7	2.0	11.7	8.1	1.3	9.4	7.1	1.4	8.5
NSF	19.0	1.8	20.8	18.0	5.1	23.1	16.7	6.2	22.9	41.3	10.0	51.3
USDA	1.8	0.0	1.8	3.2	0.0	3.2	2.2	0.0	2.2	6.0	0.4	6.4
TOTAL	**151.0**	**31.9**	**182.8**	**147.4**	**45.4**	**192.8**	**199.3**	**51.5**	**250.8**	**189.5**	**40.9**	**230.5**

The following is a small, representative sampling of the hundreds of SBIR and STTR topics funded by NNI participating agencies in 2023 that are supporting the development and application of nanotechnology R&D with potential for commercialization:

- Lightweight, multifunctional carbon nanomaterial electromagnetic interference-shielded coatings (DOW).
- Infrared windows for hypersonic vehicles enabled by metal oxide nanopowders (DOW).
- Nanoarchitected plant-cellulose-based supercapacitors for missile defense (DOW).
- Metamaterials for multispectral cloaking of combat vehicles (DOW).
- Advanced manufacturing of metal organic framework (MOF)-based hydrogen storage tanks (DOE).
- Printed indium inks for high-density chip interconnects (DOE).
- Nanocomposite scintillators for physics research and radiation monitoring (DOE).
- Optical NMR quantum sensing enabled by nanodiamond particles for imaging metabolic processes in living cells (DOE).
- Anti-fog coatings for spacesuit helmets enabled by nanotextured superhydrophobic materials (NASA).

[10] 2004 was the first year that the NNI began collecting SBIR/STTR data.

- Carbon nanotube-reinforced composites for insulated cryogenic hydrogen storage (NASA).
- Next-generation spacecraft water monitoring enabled by nanopore sensors (NASA).
- Ultradark carbon nanotube coatings for stray light control in telescopes for exoplanet detection (NASA).
- Nanopore arrays for multiparameter analysis of extracellular vesicles (particles released by cells) that can be used to identify disease-specific biomarkers (NIH).
- Solid lipid nanoparticles for sustained-release naloxone to prevent opioid overdoses (NIH).
- Gold nanoparticles conjugated with tissue grafts to enhance tissue integration and reduce inflammation (NIH).
- Nanoparticle-enhanced chemotherapy and immune therapy for treatment of pancreatic cancer (NIH).
- Luminescent quantum-dot greenhouse glass for improved crop yields (USDA).
- Value-added graphene materials from wood sources (USDA).
- Novel peptides for controlling invasive pest ants (USDA).
- Nanocomposite hydrogel thin films for rapid, low-cost water-quality monitoring (USDA).
- Printable carbon nanotube dielectric inks for flexible hybrid electronics (NIST).
- Gravure printing of nanotechnology-enabled chemical sensors (NIST).
- High-frequency (GHz) scanning electron microscope-based nanoprobes for semiconductor failure analysis (NIST).
- Cold cathode electron field emitters for imaging and communications systems, enabled by nanoporous silicon carbide (NIST).
- Handheld graphene-based sensors for rapid detection of Salmonella (NSF).
- Nanoporous filters for selective extraction of gold and other valuable metals from wastewater (NSF).
- Atomically tunable memristors and superconducting quantum interference devices for neuromorphic computing (NSF).
- Affordable point-of-use water disinfection through mass-produced nanosilver-embedded paper filters (NSF).

3. Highlights of NNI Progress and Plans

The five NNI goals are closely tied to the five PCAs that are the categories for reporting investments toward advancing those goals. This chapter of the report includes selected highlights illustrating progress toward each of the NNI goals. These highlights are followed by brief summaries of the current and future investment plans of the NNI participating agencies for the corresponding PCAs that support the goals. The examples are intended to be an illustrative sampling, not a comprehensive list, of relevant Federal agency activities. For more information and additional highlights, please see Nano.gov.

Progress on Goal 1. Ensure that the United States remains a world leader in nanotechnology research and development.

Central to the NNI is support for nanotechnology R&D, from the fundamental discoveries that expand the boundaries of knowledge to the applied and translational breakthroughs that enable new products and help improve the lives of all Americans. The NNI agencies utilize a variety of R&D support mechanisms (e.g., grants, contracts, cooperative agreements, intramural research) within their respective missions. Interagency coordination facilitated through the NNI leverages these individual efforts and prevents duplication, nurturing a nanotechnology R&D community that makes important advances in a wide range of areas of fundamental and applied science. Just a few selected examples of NNI progress under Goal 1 are highlighted below.

Eliminating the need for rare-earth elements in permanent magnets. NSF supported university research using a quantitative phase field model to unravel the mechanism underlying nanostructure formation.[11] Using this approach the research team developed a novel permanent magnet composed of earth-abundant elements (iron, aluminum, nickel, cobalt) that can outperform other permanent magnets at high temperatures. These magnets will reduce U.S. dependence on rare-earth elements, improving economic and national security.

Harnessing precision nanoelectronics and nanomedicine to treat retinal disease. NIH's National Eye Institute (NEI) has been exploring nanoscale strategies for neural interfacing and gene correction to support vision restoration and the treatment of inherited retinal diseases. Researchers are developing NanoElectronic Threads (NETs), ultrathin and flexible electrodes, to enable stable, high-resolution microstimulation of vision-related neural circuits. These nanoengineered devices are composed of biocompatible conductive polymers and thin-film metals integrated onto nanoscale substrates to reduce tissue displacement and chronic inflammation while enabling precise stimulation and recording from deep visual relay centers such as the lateral geniculate nucleus.[12] NIH/NEI also supported the development of engineered nanocarriers that are based on naturally occurring nanoparticles (i.e., engineered extracellular vesicles, EEVs). Large-scale *in vitro* screening helped identify highly neuroprotective, anti-inflammatory nanoparticles that targeted cell types specifically affected in such common, chronic vision impairments as glaucoma and diabetic retinopathy.

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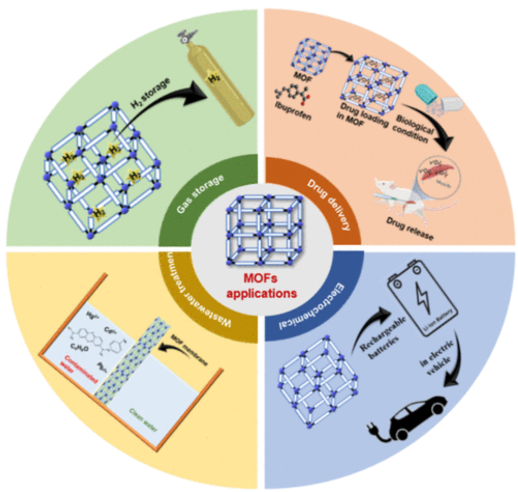
[11] doi.org/10.1038/s41598-022-08484-7
[12] doi.org/10.1038/s41467-025-62069-2

Importantly, this rapid screening system for EEVs can readily be applied to discover effective new treatments for a spectrum of human health conditions.[13]

Metal organic frameworks win 2025 Nobel Prize in Chemistry



Common metal-organic framework structure and its applications. Image credit: S.K. Kailasa (Creative Commons).

American scientist Omar M. Yaghi and two international scientists won the 2025 Nobel Prize in Chemistry for the development of metal organic frameworks. MOFs are a family of tunable nanomaterials composed of metal ions linked by organic molecules. MOFs are characterized by flexible rational design, enabling a high-porosity crystalline structure and strong chemical and thermal stability. Due to their high porosity, MOFs have a huge surface area, which makes them ideal candidates for catalysis, separation, gas storage, environmental remediation, energy storage and conversion, sensors, and molecular recognition. For example, a few grams of MOF-5 can absorb enough material to cover a soccer field while maintaining stability up to 500 degrees F.[14] *Nanoscale MOFs are also being investigated for drug delivery and other biomedical purposes, with funding from NIH.*

MOFs were first discovered in the late 1980s, and more than 100,000 different MOFs have been synthesized to date. Some are commercially available for carbon dioxide capture (zinc-based Calgary Framework 20 [CALF-20]), water harvesting (aluminum-based MOFs [MOF-303]), and removal and storage of hazardous gases (zirconium and aluminum-based MOFs).[15] *Work is ongoing at American companies to address challenges to scale-up and commercialization, including large-scale synthesis and activation of the target MOF.*

Dr. Yaghi's MOF research has received funding from the National Science Foundation, the Department of Energy, and the Department of War, among others.

Developing metal-free MRI contrast agents and nanoparticle gels for enhanced image-guided therapy. NIH's National Institute of Biomedical Imaging and Bioengineering (NIBIB) supports research efforts that use nanotechnology to improve both diagnostic imaging and image-guided therapy. One effort has focused on creating safer magnetic resonance imaging (MRI) contrast agents using highly stable triarylmethyl radical dendrimer-based nanoparticles, providing a biodegradable and metal-free alternative to traditional gadolinium agents, which are suspected of causing human toxicity, particularly in patients with kidney disease.[16] These novel nanotechnology-enabled contrast agents will not only enhance MRI imaging through high relaxivity but will also incorporate fluorescent tagging for dual MRI/optical imaging.[17] In another project, researchers are developing a novel ultrasound gel made from magnetic nanoparticles to improve the accuracy of MRI-guided focused ultrasound treatments. Transcranial MRI-guided focused ultrasound (tMRgFUS) offers a non-

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[13] doi.org/10.1016/j.actbio.2023.01.014
[14] www.energy.gov/science/articles/doe-office-science-supported-scientist-wins-nobel-prize-chemistry; doi.org/10.1038/46248
[15] doi.org/10.1038/s41563-025-02147-4
[16] doi.org/10.3390/jcm10020271
[17] reporter.nih.gov/search/UiTeq7YOG0qUY_ImMfZL_A/project-details/11086793

invasive solution to treat neurological disorders like Parkinson's disease and brain tumors. Unlike conventional water-based gels, which often interfere with MRI signals, this novel iron-based coupling medium is designed to preserve image clarity while maintaining the acoustic performance necessary for effective treatment.[18]

Detecting multiple diseases quickly and inexpensively with a single drop of blood. University researchers supported by NIH, NSF, and USDA have developed a new diagnostic tool that could transform how quickly and reliably diseases such as COVID-19, Ebola, AIDS, and Lyme disease can be detected. The test uses a single drop of blood, costs $2, and delivers results in 15 minutes. The new diagnostic device, called Nanoparticle-Supported Rapid Electronic Detection (NasRED), is simple and portable enough to be used almost anywhere—from remote rural clinics to busy urban hospitals. The tool provides lab-quality accuracy without expensive equipment and does not require specialized training. At the core of the new test are tiny gold nanoparticles engineered to detect very small amounts of disease-related proteins. The device is so sensitive it can detect disease even when only a few hundred molecules are present in a tiny fluid sample. This concentration is nearly 100,000 times lower than what standard laboratory tests require, enabling early detection of diseases with very small (6 µL) sample volume and delivery of test results in less than 15 minutes.[19]

Harnessing light-powered nanoscale electrical currents to propel emerging technologies. Scientists at Los Alamos National Laboratory's Center for Integrated Nanotechnologies NSRC are developing nanometer-scale light-based systems that could deliver breakthroughs for ultrafast microelectronics and night-vision capabilities. The scientists have designed and fabricated asymmetric, nanoscale gold structures on atomically thin layers of graphene. The gold structures, called nanoantennas, capture and focus light waves, forming optical "hot spots" that excite the electrons within the graphene. The hot spots are located only at the sharp tips of the nanoantennas, leading to a pathway on which the excited hot electrons flow. Potential applications include photodetectors, terahertz radiation sources, and ultra-high-speed wireless communications, computers, and microelectronics.[20]

Understanding LDL cholesterol at the nanoscale to inform future therapies. Intramural investigators at NIH's National Institute of Allergy and Infectious Diseases (NIAID), in collaboration with scientists from the National Heart, Lung, and Blood Institute (NHLBI) and the National Cancer Institute (NCI), have uncovered aspects of low-density lipoprotein (LDL) cholesterol structure and interactions with cells that have major implications for new cholesterol-lowering drug development. NIAID intramural investigators were the first to reveal nanoscale details of how apoB100, a structural component of LDL, interacts with its receptor molecule (LDLR) to enter cells. This is the first time the structure of LDLR bound to apoB100 has been revealed and provides new insights into the mechanisms of LDL uptake by liver cells, which play a crucial role in regulating cholesterol levels. This work is also increasing understanding of recycling of LDLR molecules and how variants of LDLR and apoB100 impact health. These new mechanistic insights may enable the future development of structurally informed therapies for lowering LDL.[21]

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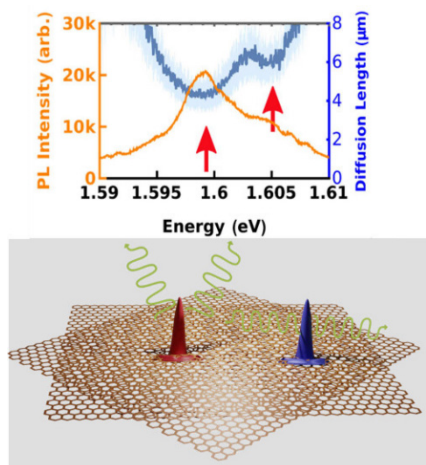
18 pmc.ncbi.nlm.nih.gov/articles/PMC9946126
19 doi.org/10.1021/acsnano.5c12083
20 www.lanl.gov/media/news/0207-nanoscale-light-driven-technology
21 doi.org/10.1038/s41586-024-08223-0

Twistronics: An emerging nanotechnology field

Novel optoelectronic properties have been observed when two layers of graphene are laid on top of each other at a slight angle, sometimes referred to as "magic angle" graphene or twisted bilayer graphene. Since 2018, research on twisted bilayer graphene has continued to grow and has led to an entirely new field called "twistronics," the study and application of novel properties of magic-angle twisted bilayer graphene and other bilayer and multilayered two-dimensional (2D) materials systems.

Over the years, researchers have continued to explore the unique properties of twisted bilayer graphene and other 2D materials. To date, researchers have observed unexpected insulating phases in magic-angle twisted bilayer graphene;[22] demonstrated that dispersion- and diffraction-free propagation is possible in twisted layers of 2D molybdenum trioxide;[23] produced dark excitons that act as qubits, and can retain information when activated by light;[24] produced rhombohedral graphene that behaves similarly to semiconductors and exhibits novel magnetism, superconductivity, and the quantum anomalous Hall effect at extremely low temperatures;[25] and developed a machine that can twist thin materials at will, avoiding the need to fabricate twisted devices one by one.[26]

Twistronics covers a vast potential application space. High-temperature superconductors (>77K) could provide critical improvements to fusion power systems and quantum computers. The correlated electronic states in twistronics' moiré superlattices could be used to define more robust and scalable qubits for quantum information systems. The optoelectronic and photonic properties of twistronic materials can be tunable based on the twist angle between the stacked 2D layers and layer composition, enabling the production of single-photon sources[27] and detectors[28] for quantum communications and new types of LEDs, photodetectors, and lasers. Twistronics could also enable highly sensitive sensors for electric or magnetic fields, chemicals, or radiation.



(Top) the photoluminescence spectrum and the spectral variation of diffusion length of the exciton. (Bottom) An illustration of the dark exciton. Image credit: *Nano Letters*.[24]

Accelerating progress in low-power electronics. NNI participating agencies are supporting a wide variety of research projects that could enable dramatic reductions in the amount of electricity and cooling required to power America's growing network of data centers, alleviating the power bottleneck for the accelerated development of AI and other information technologies. Options under development include optical computing and memory, 2D materials, and completely new computing architectures. Just a few of the many examples of ongoing research projects in these areas are summarized below.

22 doi.org/10.1038/s41586-020-3028-8
23 doi.org/10.1038/s41586-020-2359-9
24 doi.org/10.1021/acs.nanolett.5c00456
25 doi.org/10.1126/science.adk9749
26 doi.org/10.1038/s41586-024-07826-x
27 doi.org/10.1103/PhysRevLett.131.183801
28 doi.org/10.1126/science.adu5329

University and DOE National Laboratory researchers supported by the Defense Advanced Research Projects Agency (DARPA), NSF, and DOE have made an important advance toward next-generation optical computing and memory that is faster and more energy-efficient than conventional CMOS devices with the discovery of luminescent nanocrystals that can be quickly toggled from light to dark and back again. They developed materials known as avalanching nanoparticles that exhibit intrinsic optical bistability. The switching and memory capabilities of these nanocrystals have potential applications to ultra-fast and energy-efficient optical processing and information storage.[29]

University scientists supported by the Office of Naval Research (ONR), the Army Research Office (ARO), NSF, and the National Aeronautics and Space Administration (NASA) have demonstrated a basic computer capable of simple operations without using silicon-based transistors, instead using 2D materials: molybdenum disulfide n-type transistors and tungsten diselenide p-type transistors. Unlike silicon-based transistors, the performance of these materials does not degrade as their dimensions are reduced into the sub-10 nm range; they maintain their exceptional electronic properties at single-atom thicknesses. This work is a step towards thinner, faster, and more energy-efficient electronics. The team has fabricated CMOS devices using these materials that have ultra-low power consumption in the picowatt range and a switching energy as low as ~100 picojoules.[30]

Another university team, supported by ARO and NSF, has developed a framework for designing scaled three-dimensional (3D) transistors using 2D semiconductors. After considering a number of candidate 2D materials, trilayer tungsten disulfide was selected as the most promising material, with an improvement in energy–delay product of over 55% compared with silicon devices. The team demonstrated that these 2D materials can be engineered to create 2D field-effect transistors with a nearly 10x improvement in integration density and drive current over both 2D- and silicon-based 3D field-effect transistors with similar footprints.[31]

While most current AI systems operate on large arrays of conventional CMOS microelectronic circuits operating in parallel (i.e., graphics processing units, GPUs), these systems use large amounts of electricity and require extensive cooling systems. In contrast, the human brain, using much less power, can process information without predefined algorithms by learning in real time. The synaptic connections in the brain can be modified while performing a task, which can be modeled as Super-Turing computing.[32] A team of university and Air Force Research Laboratory (AFRL) researchers supported by the Air Force Office of Scientific Research (AFOSR) and NSF has developed a novel computing architecture of nanoscale synaptic resistor circuits using ferroelectric HfZrO materials, capable of concurrent real-time inference and learning and enabling artificial Super-Turing computing. They demonstrated the system by navigating a drone toward a target position while avoiding obstacles in a simulated environment, exhibiting significantly superior learning speed, performance, power consumption, and adaptability compared to computer-based artificial neural networks.[33]

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[29] doi.org/10.1038/s41566-024-01577-x
[30] doi.org/10.1038/s41586-025-08963-7
[31] doi.org/10.1038/s41928-024-01289-8
[32] doi.org/10.1016/j.pbiomolbio.2013.03.013
[33] doi.org/10.1126/sciadv.adr2082

Drawing inspiration from Nature to create novel impact-resistant nanomaterials

NIST scientists studied the exoskeletons of crustaceans to understand how the layered and rotated microstructure (called a "Bouligand" structure) imparts such remarkable strength and impact resistance to their shells. They then synthesized similar structures from cellulose nanocrystals made from plant fibers. The nanocrystals self-assembled into plates, which layered on top of each other, forming synthetic Bouligand structures. The researchers modified the crystals using high-frequency sound waves and assembled them into thin films. They tested the impact resistance of the thin films by firing silica microprojectiles at them at speeds of up to 600 meters per second, recording images of the microprojectiles impacting the thin films with an ultrafast camera.

The scientists could adjust how the impact energy dissipated by fine-tuning the thickness or density of the nanocrystals. The microprojectiles left permanent indentations in the thinner films, but the thicker films excelled at redirecting the shockwaves from the impact.

The measurement methods developed for this project can be used to further develop other impact-resistant materials, consistent with NIST's mission to develop advanced measurement methods that can be useful to U.S. industry.[34]

Three-dimensional (3D) model of a Bouligand structure. Image credit: E.P. Chan, NIST.

Realizing the promise of high-performance, lightweight nanomaterials. Researchers supported by DOW and other agencies have made significant progress in developing novel high-performance nanomaterials for a variety of potential applications. Just a few examples are summarized below.

University scientists supported by DARPA, NSF, NIH, and a private foundation have invented a new, efficient and scalable polymerization process to produce the world's first 2D mechanically interlocked polymer, containing 100 trillion mechanical bonds per square centimeter—the highest density of mechanical bonds ever achieved. Exhibiting a structure that resembles chainmail, but at the nanoscale, the material cannot easily rip because of the many mechanical bonds that would have to break; it can dissipate applied forces in many directions. This novel polymer could be used to develop composites for lightweight body armor or ballistic fabrics.[35]

Researchers from the Army Research Laboratory (ARL) and a university, with funding from ARO and NSF, have developed a nanocrystalline copper-tantalum (Cu-3Ta) alloy with ultra-small grains that limit the movement of dislocations in the material that occur on impact. The movement of the dislocations is further confined by the inclusion of nanoscale clusters of tantalum inside the grains. These innovations prevent brittle failure that normally occurs in alloys of this type on high-speed impact. Potential applications include automobiles, aircraft, and armor that are resistant to damage from high-speed impacts, extreme heat, and stress.[36]

Another ARL-university team (also funded by NSF and ARO) has developed a nanostructured copper (Cu-Ta-Li) alloy with exceptional thermal stability and mechanical strength, combining copper's excellent conductivity with the strength and durability of nickel-based superalloys. Cu_3Li precipitates and a Ta-rich atomic bilayer in the alloy act as structural stabilizers, maintaining the nanocrystalline structure, preventing grain growth, and

34 doi.org/10.1073/pnas.2425191122 , www.nist.gov/news-events/news/2025/06/bioinspired-materials-can-take-punch
35 doi.org/10.1126/science.ads4968
36 doi.org/10.1038/s43246-025-00757-8

dramatically improving high-temperature performance. The alloy holds its shape under extreme, long-term thermal exposure and mechanical stress, resisting deformation even near its melting point. Potential applications include hypersonics and high-performance turbine engines.[37]

Exploring the Universe. Nanotechnology is helping NASA build smaller, lighter, and more powerful tools for flight, science, and exploration. Researchers are developing nanoscale materials to make spacecraft more heat-resistant and with better radiation shielding. Special nanoparticles will help keep water systems clean, and nanoscale coatings can reduce dust buildup on lunar surfaces. For NASA science missions, nanoengineered optics are being developed to allow telescopes to directly image planets around other stars, while chip-sized spectrographs and interferometers are replacing bulky lab equipment. Quantum dot sensors can even be printed directly onto solar sails, combining the spacecraft and its instruments into one. Superconducting nanofilms enable highly sensitive detectors that can capture light across a wide range of wavelengths, from x-rays to far-infrared, allowing imagery in the farthest known reaches of the Universe.

Achieving enhanced performance and novel functionality with 3D-printed nanomaterials. A team of national laboratory and university scientists supported by NSF, DOE, DOW, NIH, and a State government have developed a process for 3D printing of copolymer-inorganic nanoparticle inks that self-assemble as they are 3D printed, using facilities funded by DOE and AFRL. Heat treatments then convert the printed materials into porous crystalline superconductors. This scalable process creates superconducting materials with structure at three different scales: (a) atomic scale (where atoms line up into a crystalline lattice); (b) block copolymer self-assembly (which directs the formation of mesostructured lattices); and (c) 3D printing of macroscopic lattices (e.g., coils or helices, depending on the desired applications). As a result of its nanostructured porosity, a 3D-printed niobium-nitride superconductor displayed an upper critical magnetic field of 40–50 Tesla, the highest confinement-induced value ever reported for this material, and an important figure of merit for superconducting magnets (e.g., for MRI imaging). Other potential applications of this approach to scalable fabrication of porous functional inorganic materials include catalysis, sensing, and microelectronics.[38]

Another team of university researchers supported by DOE and NSF has developed a process called hydrogel infusion-based additive manufacturing (HIAM), where parts are first printed as hydrogels using stereolithography or digital light processing. Printed structures are infused with metal ions, then heated to remove the water and polymer network while growing the inorganic metal oxides. These oxides are then reduced to the parent metal through gas-solid reactions. Copper-nickel alloy structures fabricated using this process have shown nanoindentation hardness of up to 200% higher than similar alloys processed using conventional fabrication methods. Moreover, this technique allows for fabrication of complex, multiscale hierarchical structures, and avoids potential issues such as incomplete fusion or hot cracking that can arise in parts fabricated using conventional metal 3D printing techniques (e.g., laser powder bed fusion or directed energy deposition).[39]

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[37] doi.org/10.1126/science.adr0299
[38] doi.org/10.1038/s41467-025-62794-8
[39] doi.org/10.1002/smll.202501320

Plans for PCA 1. Foundational Research

Foundational research continues to be the largest area of NNI investment, accounting for over 49% of the proposed NNI total for 2026. DOW and DOE are the largest contributors to this PCA by dollar amount, followed by NIH, NSF, NASA, NIST, the National Institute of Food and Agriculture (NIFA), and FDA. Some illustrative examples of relevant programmatic activities are provided below; this is not a comprehensive list.

DOW supports foundational nanotechnology research both through extramural funding from agencies such as the Air Force Office of Scientific Research,[40] the Office of Naval Research,[41] and the Army Research Office,[42] as well as through intramural research at in-house DOW laboratories—e.g., the Air Force Research Laboratory, the Naval Research Laboratory (NRL), and the Army Research Laboratory.[43] In addition, foundational nanotechnology research is funded by the Defense Advanced Research Projects Agency, the Defense Threat Reduction Agency (DTRA), the Chemical and Biological Defense (Chem/Bio) program, the Space Force, and the Office of the Undersecretary of War for Research and Engineering (OUSW/R&E).[44]

For example, in 2026, AFOSR plans to support a broad portfolio of nanoscience basic research, attracting top scientists to work on DOW-relevant projects focused on developing nanotechnology-enabled advanced materials. These research efforts, including 2D materials, nanocomposites, quantum devices, high-temperature ceramics, and bio-inspired materials, have the potential to enable enhanced sensors, robust electronics, and novel protection systems for air and space assets. In support of the Space Force, AFOSR plans to support basic research that advances nanophotonic sciences through the exploration of frequency-comb-enhanced heterodyne spectroscopy and high-efficiency soliton microcombs to improve spectral measurement and timing precision for potential applications in space-based sensing and communications. Additional Space Force work will explore the nanoscale manipulation of quantum states in solid-state defects using electromechanical materials, potentially enabling novel applications in quantum sensing, computing, and secure communications. Other examples include research at NRL on plasmonic light valves, and work at the Army's Institute for Soldier Nanotechnologies on 2D electronics, particularly on new materials that enable energy-efficient computing and don't require the use of silicon. The Chem/Bio program is supporting research to discover and characterize reactive/catalytic nanostructured materials for potential chemical or biological detection, protection, and hazard mitigation.

DOE supports fundamental nanotechnology R&D, including research in chemical sciences, geosciences, and biosciences and in materials sciences and engineering. It is also includes research conducted at the Nanoscale Science Research Centers (where infrastructure investments are reported under PCA 3); Energy Frontier Research Centers;[45] Energy Innovation Hubs;[46] and National Quantum Information Science Research Centers.[47]

NIH PCA 1 investments include research supported by the National Cancer Institute, the National Institute of Biomedical Imaging and Bioengineering, the National Eye Institute, the

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40 www.afrl.af.mil/About-Us/Fact-Sheets/Fact-Sheet-Display/Article/2282103/afosr-funding-opportunities
41 www.nre.navy.mil/work-with-us/funding-opportunities
42 arl.devcom.army.mil/who-we-are/aro
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44 www.darpa.mil, www.dtra.mil, www.acq.osd.mil/ncbdp/cbd, www.cto.mil
45 science.osti.gov/bes/efrc
46 science.osti.gov/bes/Research/DOE-Energy-Innovation-Hubs
47 science.osti.gov/Initiatives/QIS/QIS-Centers

National Institute of Allergy and Infectious Diseases, the National Heart, Lung, and Blood Institute, the National Institute of Environmental Health Sciences (NIEHS), the National Human Genome Research Institute (NHGRI), and the National Institute of Dental and Craniofacial Research (NIDCR), among many others. NCI provides support for basic, applied, and translational research in cancer nanotechnology. In particular, the funding opportunity, Innovative Research in Cancer Nanotechnology,[48] covers mechanistic studies contributing to fundamental understanding of nanoparticle design rules and mechanisms behind their *in vivo* interactions. NIAID supports the development of nanotechnology-enabled advances to diagnose, treat, and prevent infectious diseases. For example, NIAID-supported scientists are developing a long-acting combination antiretroviral therapy for treatment of young children with HIV based on a scalable, drug-combination nano-platform technology called drug combination nanoparticles, or DcNPs. NIAID will continue to support the application of nanotechnologies to advance understanding of human immune system development and function and the development of nanobody and immune-modulatory (e.g., adjuvant) agents to treat or protect against a wide variety of infectious, allergic, and immune-mediated diseases. NIAID is also conducting independent lipid nanoparticle discovery research to gain insight into the current industry-standard lipid nanoparticle technology, with the goal of building better nanoparticles for human use.

NIDCR continues several strategic investments in nanotechnology-based initiatives to support its broad mission of improving dental, oral, and craniofacial (DOC) health. NIDCR leverages its investments on significant promise of nanotechnology as an invaluable tool to produce novel structures that induce regeneration and repair of biological tissues, deliver biomolecules to tissues with pre-defined kinetics, and control tissue infection and inflammation, among other uses. Additional NIDCR-supported nanotechnology research focuses on advancing precision imaging for enhanced diagnosis and treatment of oral lesions; digital twins for advancing innovation and optimizing clinical outcomes in DOC medicine; organs-on-a-chip in DOC research; and accelerating product excellence in innovation and for clinical adoption.

NIBIB supports nanotechnology research and development that spans the breadth of biomedicine, including nanomaterials for drug delivery, devices, diagnostics, and novel forms of therapy. Foundational nanotechnology research investments at NIBIB are geared at elucidating underlying mechanisms of nanomaterial interfaces with biological systems and how that knowledge can be applied translationally toward the development of platform technologies of biomedical relevance. NHLBI is currently funding eight projects focusing on the development of novel therapeutic nanomaterials for heart, lung, and blood diseases and sleep disorders, e.g., a project to design and optimize a nanoparticle-based blood substitute that mimics red blood cells, with high hemoglobin payloads and physiological binding properties.[49] NIEHS encourages and supports research into the underlying properties of engineered nanomaterials to determine their potential biocompatibility or toxicity to human health.[50] NIEHS is expanding its research aimed at characterization of nano- and microplastics to address potential health issues.

NEI's mission to eliminate vision loss has been revolutionized by the emergence of nanotechnology. New nanoparticle-derived carriers are enabling more directed, controlled, and specific drug delivery and gene therapy approaches, and new nanomaterials are serving as the basis for creating more effective neuro-modulatory prosthetic devices. Efforts to improve

[48] grants.nih.gov/grants/guide/pa-files/PAR-25-106.html
[49] reporter.nih.gov/search/o0dyTJVs2kGyUbE2_8yBHA/project-details/11047274
[50] www.niehs.nih.gov/research/supported/exposure/nanohealth

spatiotemporal specificity and sensitivity for clinical trials are in progress and will be applicable to a wide variety of human diseases. NHGRI is expanding its portfolio supporting discoveries toward improving existing and developing new technologies for nucleic acid and protein sequencing utilizing nanotechnology. Within NHGRI's Genome Technology Program,[51] both new and existing projects utilize nanotechnologies such as biological and solid-state nanopores, zero-mode-waveguides, and atomic force microscopy for sequence determination and accuracy improvements.

NSF supports fundamental nanoscale science and engineering research in and across all disciplines throughout all the research and education directorates. Several new directions planned for 2026 include research connected to energy generation and storage (e.g., engineering sustainable materials, nanostructured materials, nanostructured catalysts), advanced nanomanufacturing, artificial intelligence and quantum systems, biotechnology and bioeconomy, and quantum biology. Nanotechnology research will contribute to and synergize with NSF's research supporting emerging technologies such as next-generation semiconductors and microelectronics, advanced wireless, and quantum computing. NSF has sponsored an annual nanoscale science and engineering (NSE) grantees conference to assess progress in nanoscience and nanotechnology and facilitate identification of new research directions. The theme of the 2024 NSE Conference was AI-Nanotechnology Convergence.

In 2026, NSF support will expand convergence research and education activities in confluence with other priority areas such as the Networking and Information Technology Research and Development (NITRD) Program, the National Quantum Initiative (NQI); artificial intelligence; the Materials Genome Initiative (MGI, including the Designing Materials to Revolutionize and Engineer our Future program);[52] smart systems; quantum information science and engineering; and synthetic biology. Plans and priorities for PCA 1 in 2025–2026 include continued support for fundamental research on 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 nanomanufacturing.

Foundational research in nanotechnology is a core enabler for NASA's future missions and aeronautics research; investments in 2026 span a broad range encompassing materials, optics, quantum devices, and structures. One example is the development of metamaterials for remote sensing instruments. NASA Goddard Space Flight Center is developing a meta-lens made from nanoscale structures that fold for launch and deploy as large-diameter collecting optics for LIDAR telescopes to measure atmospheric moisture and winds. NASA's Jet Propulsion Laboratory, in collaboration with a public research university, is developing metasurface antennas using engineered artificial dielectric materials to control electromagnetic waves with structured materials to study planetary boundary layers and snowpacks.

NIST is advancing nanoscale measurement science, standards, and nanotechnology as an important component of its mission to promote U.S. innovation and industrial competitiveness. From leading cutting-edge research to coordinating the development of standards that

[51] www.genome.gov/Funded-Programs-Projects/Genome-Technology-Program

[52] www.nsf.gov/funding/opportunities/dmref-designing-materials-revolutionize-engineer-our-future

promote trade, NIST's programs in nanotechnology directly impact priorities important to the Nation's economy and well-being.[53] Foundational nanotechnology research at NIST covers a wide variety of topics, including nanoelectronics, nanofabrication/manufacturing, nanofluidics, nanomaterials, and nanometrology.[54] NIST PCA 1 investments also include foundational research related to semiconductors and microelectronics (see PCA 2 section below for additional details).

USDA/NIFA will continue to fund foundational and applied nanotechnology research in 2025 and 2026. Funding will occur through NIFA's flagship funding line, the Agriculture and Food Research Initiative (AFRI) Foundational and Applied Science Program,[55] which includes a program entitled Nanotechnology for Agricultural and Food Systems (A1511). Nanotechnology-related projects are funded across the AFRI portfolio (e.g., A1103 Foundational Knowledge of Plant Products, A1112 Pests and Beneficial Species in Agricultural Production Systems, etc.). Priorities under PCA 1 include the discovery and characterization of nanoscale phenomena, processes, and structures relevant and important to agriculture and food. Examples of the broad research topics NIFA supports include nanotechnology-enabled sensors for the monitoring of soil-plant-animal pathogen-environmental interactions, investigations of plant virus nanoparticle technology for use as plant vaccines, using sustainable nanomaterials to enhance the efficacy of natural antimicrobials, nanocellulose-metal organic frameworks for sensing and degrading agrochemicals, synthesis of few-layer graphene-encapsulated iron nanoparticles from agricultural wastes, exploration of cellulose nanocrystals for detection of allergens and emerging contaminants, and use of multiscale modeling and machine learning for design and characterization of chitosan-based nanocomposites.

FDA invests in nanotechnology research in PCAs 1, 2, and 5 to help address questions related to the safety, effectiveness, quality, and/or regulatory status of products that contain engineered nanomaterials or otherwise involve the use of nanotechnology. FDA also invests in research to develop models for safety and efficacy assessment, as well as to study the behavior of nanomaterials in biological systems and their effects on both human and animal health. FDA's Human Foods Program (HFP) has been involved in research on various nanotechnology-related areas relevant to human food safety, including studies on the potential migration of engineered nanomaterials from nanotechnology-enabled food contact materials to food or food simulants, research on possible incidental presence of nanoparticles in certain food additives, and development of nanotechnology-enabled sensors. HFP has a cooperative research and development agreement (CRADA) with DOE's Fermi Accelerator Laboratory (FermiLab) to understand links between e-beam irradiation (a packaging sterilization technology) and migration of nanoparticles from model packaging materials to foods (CRADA 2021-0008-CRD). HFP's working group on micro-/nanoplastics (MNPs) in food brings together subject matter experts, policy analysts, regulatory scientists, and communications staff across FDA to foster communication within HFP regarding MNPs, monitor the state of the science, propose and coordinate research projects, advise agency leadership, and engage with external stakeholders.

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[53] www.nist.gov/nanotechnology

[54] www.nist.gov/nanobiotechnology, www.nist.gov/nanochemistry, www.nist.gov/nanoelectronics, www.nist.gov/nanofabrication-manufacturing, www.nist.gov/nanofluidics, www.nist.gov/nanomagnetics, www.nist.gov/nanomaterials, www.nist.gov/nanomechanics, www.nist.gov/nanometrology, www.nist.gov/nanophotonics, www.nist.gov/nanophysics, www.nist.gov/nanoplasmonics

[55] www.nifa.usda.gov/grants/funding-opportunities/agriculture-food-research-initiative-foundational-applied-science

FDA is a member, and currently serves as the chair, of the International Pharmaceutical Regulator Program Nanomedicine Working Group. This is a collaborative effort among 17 international regulatory agencies aimed at facilitating regulatory convergence, sharing information and best practices, and addressing scientific and regulatory challenges specific to nanomedicines. The group conducts four webinars annually and operates two active subgroups. The first subgroup focuses on doxorubicin-HCl liposome product-specific guidance, developing an informative document on regulatory requirements for generic/follow-on liposomal doxorubicin products and conducting comparative analyses of regulatory landscapes. The second subgroup, dedicated to lipid nanoparticles (LNPs), has reached consensus on determining active pharmaceutical ingredients and excipients in LNPs, as well as the biological or chemical product classification of mRNA and LNPs. This subgroup has also analyzed similarities and differences between LNPs and liposomes, and is actively collecting and sharing non-confidential regulatory information within the working group.

FDA's Nanotechnology Task Force facilitates communication and cooperation across the agency on nanotechnology research, and with national and international stakeholders. It provides the overall coordination of FDA's nanotechnology research efforts in the following programmatic investment areas: scientific staff development and professional training, laboratory and product-testing capacity, and collaborative and interdisciplinary nanotechnology research.

Progress on Goal 2. Promote commercialization of nanotechnology R&D.

Federal investments in nanotechnology R&D have led to thousands of products in the marketplace, and today's scientific discoveries serve as the foundation for the next generation of applications. The NNI fosters commercialization by sharing information, promoting access to user facilities, leveraging resources through public-private partnerships, and participating in international standards activities that are critical to commercialization. In addition to these mechanisms, NNCO has a staff member dedicated to liaison with industry who conducts outreach, shares best practices, and supports collaborations as appropriate. A few examples of progress on Goal 2 are shown below.

Bringing nanotechnology biomedical innovations to market. NIH is investing in small business innovation through its SBIR and STTR programs, with a strong emphasis on bringing new biomedical innovations to market, supporting projects that translate biomaterials-based innovations into clinically and commercially viable products, while addressing challenges such as regulatory hurdles, limited funding access, and scalability. Almost every NIH institute and center has funded translational nanotechnology research through the SBIR and STTR programs. Many of the 2025 SBIR/STTR awards focus on biomaterials, regenerative medicine, and tissue engineering, aiming to improve treatments for conditions like fibrosis, heart disease, and traumatic injuries. A Notice of Special Interest: Translating Biomaterials-Based Technologies to Commercially Viable Products[56] (now completed) resulted in the funding of nanotechnology-based approaches such as nanoparticle contrast agents and nano-biomaterials for protein purification. Consistent with the Administration's Make America Healthy Again (MAHA) initiative, NIH has been supporting research to detect contaminants in water and air. For example, NIEHS has funded SBIR projects to develop and commercialize a

[56] grants.nih.gov/grants/guide/notice-files/NOT-EB-24-001.html

graphene-based real-time sensor for measurement of lead in drinking water; an integrated smartphone-nanosensor platform for point-of-care biomonitoring of human exposure to pesticides; a new "nanosafe" tested facilities program to quantify and reduce airborne ultrafine particulates, micro-/nanoplastics, and engineered nanomaterials; and graphene and metal-organic frameworks for detection of per- and polyfluoroalkyl substances (PFAS). NIDCR has been supporting the Dental, Oral and Craniofacial Tissue Regeneration Consortium (DOCTRC),[57] which is an excellent example of long-standing support by NIDCR of nanotechnology development. This consortium is helping to advance promising technologies, including nanotechnology-based approaches for regeneration and reconstruction of DOC tissues. The DOCTRC initiative was designed to shepherd new therapies through pre-clinical studies and into human clinical trials, commercialization, and broad clinical adoption. DOCTRC has supported over 40 interdisciplinary translational projects, thus facilitating introduction of nanotechnologies into clinical practice. Examples include stem cell-based therapies for bone regeneration, immunomodulatory strategies to treat periodontal disease, and remineralization treatments using nanoparticles.

Harnessing quantum dots for space exploration and military bases of the future

A company actively collaborating with the Department of Energy's Los Alamos National Laboratory is enabling increased efficiency in spacecraft power systems with its quantum dots and has entered into a partnership with another U.S. company manufacturing advanced thin-film systems. This same quantum dot company partnered with NASA, USDA, and a university to enhance the lighting component of NASA's Mars-Lunar Greenhouse prototype to improve the food production of the system.[58] Finally, this quantum dot company is working with the Air Force to increase installation energy resiliency.[59]

Artist's conception of a greenhouse on Mars. Image credit: NASA.

Highlighting nanotechnologies available for commercial development. Each month, NASA highlights stories and technologies to promote commercialization opportunities through the Agency's Technology Transfer YouTube channel. Two nanotechnology-related videos were featured recently, highlighting NASA-developed technologies that are available for licensing.[60] One of these features a scalable process to synthesize long, uniform boron nitride nanosheets, which could be integrated into numerous materials systems and applications for radiation shielding or high-power electric devices.[61] One company has been using a nanosensor platform that was originally developed by researchers at NASA Ames Research Center to provide diagnostic data about astronaut health, utilizing olfactory-mimicking capabilities enabled by nanotube arrays to detect molecular compounds in a person's breath that are disease- or condition-specific biomarkers. The device has been introduced to various markets, such as

57 doctrc.org
58 www.sbir.gov/awards/174818
59 www.sbir.gov/awards/198570
60 www.youtube.com/@NASATechTransfer/videos
61 technology.nasa.gov/patent/LEW-TOPS-179

telehealth and hospitals, and it also has other uses to detect hazards in the workplace or for military applications. In another example, researchers at NASA Langley Research Center developed a metal-infused conducting lightweight carbon nanotube (CNT) composite for lightning protection for composite aircraft structures that also has improved mechanical properties over conventional composites.[62]

NASA's SBIR contracts, awarded for their technical merit and commercialization potential, are developing nanotechnology innovations across multiple domains. Examples include carbon nanotubes to strengthen cryogenic tanks, darken coronagraph optics, and enable reconfigurable structures; nanoparticles to increase solar cell efficiency, control biofouling, enable printed electronics, and detect plant health; nitrogen-vacancy diamond centers for quantum sensors and magnetometers; superconducting nanowires for chip-scale single-photon detection; nanoporous aerogels to insulate extravehicular activity (EVA) suits; electrospun nanofibers to deliver drugs in microgravity; and nanotextured coatings for anti-fog spacesuit visors.

Other NNI-participating agencies are also making the results of their nanotechnology research available for commercial development. For example, the Federal Highway Administration (FHWA, within the Department of Transportation, DOT) pursues advances in performance, durability, and resiliency of transportation infrastructure materials through innovations in nanoscale characterization techniques and modeling material interactions at multiple scales. The research results are providing asset owners such as State departments of transportation and the U.S. construction industry with a broader palette of materials—including recycled and waste materials—with known performance, leading to improvements in infrastructure material supply chains and material cost required to build and maintain the U.S. highway system.

Predicting and improving the properties of carbon nanotube composites using computational modeling. The metal-infused CNT composites described above complement recently completed work under the NASA Superlightweight Aerospace Composites (SAC) project, which advanced the maturation and scalability of CNT-reinforced polymer composites to enable their application for aerospace structures over conventional parts often constructed of aluminum. Reducing spacecraft structural mass can provide a significant benefit by reducing mission costs for a given payload or increasing payload (and mission capability) at constant cost. The SAC project's goals included advancing the manufacturability of nanocomposites, computational modeling, composites processing, and mechanical property prediction and attainment. Successful outcomes included the establishment of several public-private partnerships, leveraging expertise from other government labs, developing stronger partnerships with small businesses, and training students from 12 university partners. The team developed and tested prototypes of the CNT nanocomposites at scale and also developed different manufacturing approaches, including optimal resin infiltration in the fibers, that took into account the unique microstructure of the CNT yarns to optimize resin-fiber load transfer at the fiber matrix interface. The processes developed led to mechanical property improvements, which were accelerated through computational modeling.[63]

Using catalytic nanoparticles to enable 3D printing of dissimilar materials. NSF-funded researchers developed a charge-programmed additive microfabrication process for multiple materials to achieve devices with multiple functionalities. They used catalytic nanoparticles

62 www.youtube.com/watch?v=i4Rt8BldxD4
63 doi.org/10.1016/j.compositesb.2024.111329

and charge-programmable polymers to enable rapid, simultaneous 3D printing and synthesis of metal and dielectric materials,[64] and developed a high-speed printing method for manufacturing complex antenna designs tailored for 5G/6G applications, achieving over 90% weight reduction over conventional antenna designs. This technology could enable the rapid manufacturing of a host of other 3D-printed electronic devices. The researchers have transitioned their research from academia into a startup company specializing in the development and manufacturing of tactile sensors and haptic devices.

Harnessing nanomaterials to enable better solid-state batteries. A significant roadblock to commercial success of solid-state batteries is expansion and contraction as the batteries charge and discharge, sometimes causing the cells to fracture. However, an early-stage company is using a nanoengineered ceramic layer to build a compressionless solid-state battery, eliminating the expansion/contraction cycles, enhancing safety, and eliminating fire hazards. This company has been funded as a participant in the Seeding Critical Advances for Leading Energy technologies with Untapped Potential (SCALEUP) program at the Advanced Research Projects Agency-Energy (ARPA-E).[65] Besides ARPA-E, the company also partners with the Army Research Laboratory and the Center for Research in Extreme Batteries, a consortium of universities, companies, and government laboratories.

Promoting standards to accelerate regulatory approval and commercialization of nanotechnology-enabled medical products. In 2025, FDA's National Center for Toxicological Research (NCTR) Nanotechnology Core Facility (NanoCore), with support from the NIH/NIEHS Division of Translational Toxicology, finalized several documentary test method standards in collaboration with the ASTM International E56.08 Subcommittee on Nanotechnology-Enabled Medical Products.[66] In late 2024 and early 2025, FDA provided technical input on two ASTM and ten International Organization for Standardization (ISO) nanotechnology standards. This contribution supported the development of final standards that can be readily recognized and efficiently implemented in regulatory processes. NanoCore collaborated with NIST on the evaluation of sources of variability on a previously published ASTM standard, "Standard Test Method for Detection of Nitric Oxide Production *In Vitro*." In addition, NanoCore has completed the analysis of data on three international inter-laboratory studies on lipid quantitation in liposomal formulations. Collectively, this body of work on standards development, evaluation, and recognition helps FDA and industry in facilitating the review of complex product submissions.

64 doi.org/10.1002/adfm.202313839
65 arpa-e.energy.gov/programs-and-initiatives/SCALEUP-program
66 e.g., doi.org/10.1520/E3483-25

Tackling "forever chemicals" with nanotechnology

Per- and polyfluoroalkyl substances, commonly known as "forever chemicals," are a group of over 8,000 synthetic organofluorine chemical compounds that do not degrade naturally due to the strong C-F bond. PFAS have been historically used in many applications such as non-stick cookware, food packaging, textiles, semiconductor manufacturing, and firefighting foam. While PFAS utilization is now limited, understanding PFAS bioaccumulation and the associated environmental and health risks is a scientific priority.[67] Multiple NNI participating agencies are supporting research, development, and commercialization of nanotechnologies to detect, collect, and destroy PFAS. For example, one company supported by DOW, the Environmental Protection Agency (EPA), NIH, and NSF developed and commercialized its nanoscale cyclodextrin technology for detecting and removing PFAS from water. The adsorbent can be regenerated for reuse, while the PFAS is extracted as a waste solid and mechanochemically mineralized into nontoxic salts. The company now offers home water filter cartridges, as well as utility-scale water treatment systems and a PFAS test kit. The Massachusetts Department of Environmental Protection has now approved the use of the company's cyclodextrins to remove PFAS from drinking water systems throughout the state. This approval followed 12 months of pilot testing in Newburyport and Lynnfield, MA, that successfully demonstrated reduction of PFAS in water to nondetectable levels. Additional pilot testing is ongoing or planned at municipal drinking water plants in seven other states.

Photograph of scientist taking water sample for testing from a wetland. Image credit: DOE.

Other companies with technology prototypes are receiving support to scale up their PFAS solutions. For example, a company supported by NASA, NIH, NSF, and DOW is developing a suite of equipment that can detect, capture, concentrate, and destroy PFAS. Two of its technologies incorporate nanotechnology. One of them is a bi-metallic zero-valent iron composite that can be used to trap and degrade PFAS through reductive chemistry. The other is using nanotechnology to develop a low-cost, high-throughput device that can detect PFAS in real time in the field using fluorescent nanoparticles and a hyperspectral fluorescent imaging instrument.

Detection of PFAS is a current limitation in remediation efforts. To address this issue, another company, supported by EPA, NIH, NSF, and USDA, is developing nanomaterial-based sensors for environmental contaminants. Its low-cost, point-of-use graphene-based nanosensor chips can detect PFAS in low concentration in water. This technology takes advantage of the unique properties of graphene to detect small changes in conductivity caused by contaminants binding to the graphene-based sensor surface. This small change in conductivity can be correlated to concentration to provide quantitative results.

Developing commercial products from cellulose nanomaterials. While the 2026 Budget does not request U.S. Forest Service (FS) funding for nanotechnology research, promising achievements occurred in 2024 and 2025. The Forest Service has been working with universities and industry to develop high-value-added products incorporating cellulose

[67] See the May 2025 Make America Healthy Again (MAHA) Report, www.whitehouse.gov/wp-content/uploads/2025/05/MAHA-Report-The-White-House.pdf, p. 43, and the September 2025 MAHA strategy document, www.whitehouse.gov/wp-content/uploads/2025/09/The-MAHA-Strategy-WH.pdf, p. 10.

nanomaterials. For example, adding cellulose nanofibril (CNF) to drilling fluids significantly improves performance (e.g., rheology, lower fluid loss, improved salt-tolerance). A commercial-scale process has been developed for manufacturing high-performance CNF drilling fluid additive as a combined rheological modifier, filtration control, and thermal/salt tolerance agent. This project has scaled up to be able to produce up to 2.5 million lbs. of the additive (using 50,000 lbs. of CNF) and is being tested in a commercial drilling rig in Arkansas. In another example, Forest Service research has shown that spraying a 2% solution of nanocellulose in water on apple and cherry blossoms allows them to survive 2–4 °C lower temperatures than conventional treatments. This product is in commercial trials in Washington State. FS researchers also have demonstrated formaldehyde-free binders for wood building products, using nanocellulose as a non-toxic and biodegradable glue for wood panels. This product has been in pre-commercial trials in Virginia, where over 170,000 sq. ft. of fiber board has been manufactured.

The Forest Service's Forest Products Laboratory is also working on industrial-scale CNF-enabled hybrid molded fiber production processes, nanocellulose biofilms with encapsulated polyphenolics for active molded pulp packaging, and polymer-modified cellulose nanofibrils for thermoplastic elastomer reinforcement. Other projects include scaling up nanocellulose-based adjuvants for sustainable pesticide delivery, functionalized nanocellulose for removal of PFAS, cellulose nanomaterials for firefighting applications, functionalized carbonyl cellulose nanofibrils for Li-ion batteries, and safety assessments for regulatory acceptance of cellulose nanomaterials.

Enabling a revolution in refrigeration. University researchers, with initial support from DARPA and in partnership with a major refrigerator manufacturer, have developed a new solid-state thermoelectric refrigeration technology using nanoengineered materials called controlled hierarchically engineered superlattice structures (CHESS). Thermoelectric refrigerators cool by using electrons to move heat through semiconductor materials, eliminating the need for moving parts or harmful chemicals, making them quiet, compact, and reliable. The new CHESS-based refrigerators are twice as efficient as current state-of-the-art thermoelectric systems. Initially developed for national security applications, CHESS has been used for noninvasive cooling therapies for prosthetics and won an R&D 100 award in 2023. This thin-film technology uses just 0.003 cubic centimeters of the CHESS materials per refrigeration unit and can be mass-produced using standard semiconductor chip production tools.[68]

Plans for PCA 2. Nanotechnology-Enabled Applications, Devices, and Systems

NNI investments in nanotechnology-enabled applications, devices, and systems (currently PCA 2) have grown in recent years, from under 24% of the total in 2016 to over 34% in the 2026 request.

PCA 2 is by far the largest category in the NIH NNI investment portfolio, accounting for nearly 77% of its 2026 request, up from just under 59% in the 2023 request.[69] Other agencies contributing to PCA 2 in the 2026 budget (in descending order of dollar amount of investments) include DOW, NSF, DOE, NIST, FDA, NASA, the Agricultural Research Service (ARS), NIFA, the Department of Justice (DOJ), and FHWA.

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[68] doi.org/10.1038/s41467-025-59698-y

[69] See www.nano.gov/sites/default/files/pub_resource/NNI-FY23-Budget-Supplement.pdf, p. 12.

NIBIB serves as the engineering hub of NIH, supporting a variety of research on engineered nanotechnology for crosscutting biomedical applications. Examples include magnetic nanoparticles boosting tumor treatment, ultrasound-triggered nanotechnology-enabled drug delivery systems, novel nanomedicines designed using AI/machine learning, and DNA-based self-propelled nanoparticles targeting biofilms. NIBIB is committed to accelerating biomaterials-based technologies, including nanomaterials, through the Biomaterials Network Technology Development Coordinating Center.[70] The center aims to address translational barriers and help novel classes of biomaterials move from discovery and preclinical research toward commercialization and clinical integration.

Several NCI-funded efforts have applied focus and are dedicated to developing new and improved diagnostics and therapeutics. Diagnostic technologies primarily prioritize high sensitivity and the capacity for multiplexed detection, enabling early and precise identification of cancer biomarkers. On the therapeutic side, in addition to nanotechnology-based chemotherapeutics, there is growing exploration of nanotechnology-enabled gene therapies and immunotherapies. The funding opportunity, Toward Translation of Nanotechnology Cancer Interventions, facilitates late preclinical evaluations, enhancing integration of nanotechnology cancer interventions into mainstream programs.[71]

NIAID is using nanoscale science to create novel systems for drug discovery, drug delivery, and infectious disease diagnostics, e.g., nanofabrication and development of an "organ-on-a-chip" system with embedded electrochemical sensors to discover new antibiotics. NIAID-supported scientists are applying metal organic frameworks to drug development for the first time. This research will develop a novel MOF antibiotic delivery system to treat non-tuberculous mycobacterial infections. NIAID also aims to develop a third-generation nanopore nucleic acid sequencing system to predict antibiotic susceptibility from a broad menu of bacterial infections, reducing time-to-result from three to six days down to nine hours. NIAID-supported scientists are also developing plasmonic gold nanoshells to maximize the analytical sensitivity of lateral flow assays, which can bring a two- to ten-fold increase in analytical sensitivity for detecting certain parasites compared to standard diagnostic tests.

NHGRI recently funded a Technology Development Coordinating Center[72] that coordinates interaction, collaboration, and dissemination of new advancements within the NHGRI Genome Technology Program. NHGRI has also supported new projects with small businesses in these same scientific areas utilizing nanotechnology for genomic analysis.

NEI has supported decades of investment in innovative approaches to ocular therapy, including those that are nanotechnology-enabled. An NEI-funded study highlights the potential of nanotechnology to restore vision in retinal disorders, including macular degeneration. The team demonstrated that gold nanoparticles injected into the retina, combined with a wearable laser device, can bypass damaged photoreceptors and stimulate downstream visual cells, effectively restoring vision in mice.[73]

DOW supports nanotechnology applications, devices, and systems research (PCA 2) through extramural and intramural funding from the Air Force (AFOSR/AFRL), Navy (ONR/NRL), Army (ARO/ARL), DARPA, DTRA, the Chem/Bio program, the Space Force, and the Coalition

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70 www.nibib.nih.gov/programs/biomaterials-network
71 grants.nih.gov/grants/guide/pa-files/PAR-25-336.html
72 genometdcc.org
73 www.nei.nih.gov/about/news-and-events/news/nei-funded-researchers-test-new-visual-prosthesis-system-restore-vision

Warfare Program (CWP). For example, AFRL is conducting research to develop nanotechnology-enabled devices and systems using nanomaterials (e.g., 2D materials, nanocomposites, quantum devices, high-temperature ceramics, bio-inspired materials) for applications such as sensors, electronics, and protection systems for air and space assets. The ONR Power Electronics program[74] is supporting the development of nanotechnology-enabled wide-bandgap semiconductor materials (e.g., SiC) for power electronics power distribution system applications, including high power and pulsed power required in modern Navy systems. It is also supporting research on additive manufacturing of ferrites for ultra-high-frequency megawatt-class magnetic devices, tunable paramagnetic and superparamagnetic materials for hybrid core inductors for shipboard power (in cooperation with Sandia National Laboratory), and boundary-engineered nanocomposites as high-frequency inductors for shipboard and airborne Navy power systems. DTRA is supporting research under PCA 2 on radiation-hardening of nanoscale microelectronics and characterization of nanoscale defects and interfaces in microelectronics. CWP has been funding research on nanomaterials for lightweight transparent armor. The Chem/Bio program is supporting applied research to discover, engineer, and integrate engineered reactive/catalytic nanostructured materials into filters, decontaminants, and textiles to assess multifunctional materials for protection and hazard mitigation in an operationally relevant environment. Research also investigates use of novel materials for microsensors to detect and identify chemical and biological threats. DARPA's PCA 2 investments include the Synthetic Quantum Nanostructures (SynQuaNon) program, which is developing novel classes of superconducting metamaterials for new capabilities in quantum information science, including "bottom-up" design and synthesis of functional quantum metamaterials for superconducting nanoelectronics. Devices and applications explored within SynQuaNon include superconducting qubits at elevated temperatures and frequency regimes; single photon detector arrays for new regimes of sensing, imaging, and communication; and quantum-limited millimeter wave signal processing architectures.[75]

For 2026, NSF will strengthen partnerships with translational NSF programs such as Innovation Corps,[76] SBIR/STTR,[77] Translation to Practice,[78] and Regional Innovation Engines,[79] which are led by the NSF Directorate for Technology, Innovation and Partnerships. Other translational innovation programs within NSF include Grant Opportunities for Academic Liaison with Industry;[80] Industry-University Cooperative Research Centers (IUCRCs);[81] and NSF INTERN,[82] managed by the NSF Directorate for Engineering, all of which strengthen workforce development for industry. The National Nanotechnology Coordinated Infrastructure also supports translational research activities.[83] Other translational programs at NSF that include a large portfolio of nanotechnology projects contributing to PCA 2 include Engineering Research Centers (ERCs),[84] Materials Research Science and Engineering Centers

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74 www.nre.navy.mil/organization/departments/code-33/power-and-energy-focus-area/power-electronics-and-electromagnetism
75 www.darpa.mil/research/programs/synthetic-quantum-nanostructures
76 www.nsf.gov/funding/initiatives/i-corps
77 seedfund.nsf.gov
78 www.nsf.gov/funding/opportunities/nsf-ttp-national-science-foundation-translation-practice
79 www.nsf.gov/funding/initiatives/regional-innovation-engines
80 www.nsf.gov/eng/eec/goali.jsp
81 iucrc.nsf.gov
82 www.nsf.gov/eng/intern
83 nnci.net. See Goal 3 and PCA 3 sections below for details.
84 www.nsf.gov/eng/engineering-research-centers

(MRSECs),[85] and Centers for Chemical Innovation (CCIs), as well as Manufacturing USA institute collaborations.[86] Related activities also include sustainable nanomanufacturing, nanoelectronics, nanosensors, and sensors to detect and quantify nanomaterials.

DOE support for R&D on nanotechnology-enabled applications, devices, and systems includes the microelectronics Energy Efficiency Scaling for 2 Decades (EES2) initiative. DOE has been partnering with multiple organizations nationwide to develop a draft EES2 R&D roadmap,[87] which identifies nanotechnology (e.g., CNT devices) among its list of high-impact technologies, and which will inform funding opportunity announcements at various DOE offices and other U.S. government agencies. EES2 lab call projects funded in 2023[88] are expected to continue through 2025–2026. DOE's CABLE (Conductivity-enhanced materials for Affordable, Breakthrough Leapfrog Electric and thermal applications) portfolio is advancing cutting-edge nanotechnology research to develop next-generation materials that enhance electrical and thermal conductivity for energy applications. Projects at DOE National Laboratories and universities leverage nanomaterials such as graphene, MXenes, and carbon nanotubes to create more efficient and durable energy infrastructure and components. Topics include incorporating MXenes into copper composites to improve the conductivity, tensile strength, and corrosion resistance of power transmission lines; aluminum ultra-conductors with graphene additives to enhance electrical conductivity for aerospace busbar applications; carbon nanotube fibers for ultra-high thermal conductivity; and advanced carbon nanomaterials with a unique combination of conductivity, strength, and flexibility, for applications ranging from lightweight transmission lines to advanced sensors. These projects highlight a comprehensive effort to harness the power of nanotechnology for breakthroughs in energy efficiency, material performance, and U.S. leadership in advanced manufacturing. Other DOE PCA 2 investments include the Carbon Ore, Rare Earth, and Critical Minerals Initiative,[89] which includes a focus on producing nanomaterials with carbon from coal.

NIST PCA 2 investments include research on quantum materials design and characterization. NIST is conducting research on nanoscale devices and systems for applications such as microelectronics, coatings, and pharmaceutical products, including how this research can underpin technical standards used by U.S. industry. This is in addition to research at the NanoFab at the Center for Nanoscale Science and Technology[90] in Gaithersburg, MD (which also serves as a user facility, see PCA 3 section below), and at the NIST Boulder Microfabrication Facility.[91]

A key element of FDA research falling under PCA 2 is contribution to the development of voluntary consensus standards, which provide clear regulatory expectations, streamline premarket review, and facilitate markets for safe and effective products, as well as promoting international harmonization. FDA provides global leadership on development, review, and recognition of consensus standards. FDA scientists and subject matter experts actively participate in the early stages of consensus standard development and review draft standards to ensure alignment with FDA regulations and expectations. This proactive involvement facilitates the safety and efficacy evaluation of medical products and helps prevent conflicts

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85 www.nsf.gov/funding/opportunities/mrsec-materials-research-science-engineering-centers
86 www.nsf.gov/pubs/2024/nsf24014/nsf24014.jsp
87 www.energy.gov/sites/default/files/2024-08/Draft_EES2_Roadmap_AMMTO_August29_2024.pdf
88 www.energy.gov/eere/ammto/fy-2023-microelectronics-lab-call
89 netl.doe.gov/resource-sustainability/critical-minerals-and-materials/core-cm
90 www.nist.gov/cnst
91 www.nist.gov/programs-projects/boulder-microfabrication-facility

between standards and regulatory requirements. FDA's National Center for Toxicological Research conducts collaborative regulatory science research to address questions related to nanotechnology and nanomaterials use in FDA-regulated products through material characterization, safety and efficacy assessment, and documentary standards development with stakeholders within FDA, other government agencies, and academia. NCTR's NanoCore, in collaboration with the NIH/NIEHS Division of Translational Toxicology, engages in international documentary standards development through ISO TC 229 (Nanotechnologies), ASTM International, and the Organisation for Economic Co-operation and Development (OECD) Working Party on Manufactured Nanomaterials (WPMN). FDA's Center for Veterinary Medicine (CVM) works internally with HFP and the Center for Drug Evaluation and Research (CDER) to develop comprehensive standards, enhancing cross-center interaction and understanding of nanotechnology. Externally, CVM partners with organizations like the United States Pharmacopeia (USP) to establish industry guidelines, potentially accelerating the development of safe, effective nanotechnology-enabled products. Also, CVM participates as an observer in the European Medicines Agency nanomedicines operational expert group.

FDA's Center for Biologics Evaluation and Research (CBER) Office of Vaccines Research and Review evaluates the safety and effectiveness of vaccines for the prevention of infectious diseases, including mRNA vaccines encapsulated in lipid nanoparticles, which have been used successfully against the virus that causes COVID-19 (SARS-CoV-2), as well as other nanoparticle-enabled vaccines such as virus-like particle (VLP) vaccines against human papillomavirus (HPV) and several protein-based vaccines being developed that are nanoparticle structures.

NASA supports research in nanotechnology to accomplish mission needs in aeronautics and space exploration. NASA's nanotechnology activities include theoretical and experimental research, which are carried out both in-house and externally through grants and contracts. NASA's nanotechnology portfolio is comprised of internal and external investments to promote technological advancements in areas such as lightweight, multifunctional aerospace structures, composite fuel tanks, spacesuit textiles, next-generation energy storage and propulsion systems, compact sensors, multispectral and advanced imaging components for instrumentation, and water sustainability on spacecraft. Current research areas where nanotechnology is making an impact include manufacturing low-power, compact sensors for chemical and biological species detection; lightweight, multifunctional materials to reduce payload and vehicular weight on spacecraft; enhanced spectral imaging instrumentation for space exploration; and advanced materials to enable power generation and energy storage. Commercialization of enabling nanotechnologies is being fostered through NASA's SBIR and STTR programs, as well as activities sponsored through the NASA Technology Transfer Program. For example, through the Aeronautics Research Mission Directorate's Transformational Tools and Technologies Project[92] on high-voltage cable insulation, rapid manufacturing and rapid process automation are being explored as a way to accelerate the development of thermally conductive polymer nanocomposite electrical insulators made with boron nitride nanosheets by incorporating artificial intelligence and machine learning platforms to help researchers optimize insulation formulations intended for long operation in high electrical and thermal stress environments. NASA is funding researchers at a research university to develop a revolutionary lightweight, high-efficiency and high-resolving-power x-ray spectrograph based on nanofabricated grating elements. Increased performance is achieved

92 www.nasa.gov/directorates/armd/tacp/ttt

through very deep grating grooves, which are fabricated using high-resolution 3D photonic imaging. This imaging technology was first developed for the James Webb Space Telescope and is now in use by the semiconductor industry to achieve extremely fine-resolution circuits. NASA's Space Technology Mission Directorate is currently re-evaluating its R&D funding priorities, based in part on the 2026 Civil Space Shortfall Ranking.[93] Based on that analysis, future investments in nanotechnology may be reflected in any number of NASA programs, e.g., NASA Innovative Advanced Concepts;[94] the Center Innovation Fund;[95] the Early Career Initiative;[96] prizes, challenges, and crowdsourcing; Announcement of Collaboration Opportunities,[97] and Flight Opportunities.[98]

USDA's Agricultural Research Service is conducting applied nanotechnology research at three of its research centers. Projects at ARS's Western Regional Research Center in Albany, CA, include research on biomass from hemp-pulped nanofibers; thermoplastic starch blends of cellulose nanocrystals/ nanofibrils; and straw residue, bagasse, and grass feedstocks for making nanocomposites and single-use packaging containers. The National Center for Agricultural Utilization Research in Peoria, IL, is conducting research on phospholipid/polysaccharide nanoparticles for food and cosmetics; using agricultural waste as feedstocks for making commercial nanocelluloses and nano-hemicelluloses; protein nanocapsules to encapsulate ingredients such as vitamin E; and nanocellulose from sorghum stover for paints and 3D printing. At the Southern Regional Research Center in New Orleans, LA, there are projects on cotton fibers incorporated with (a) silver nanoparticles for antimicrobial, thermal insulation, flame retardant, and hydrophobicity applications; (b) iron oxide nanoparticles to impart magnetic properties; and (c) copper ion nanoparticles for air and water purification applications. Each of these centers has multiple cooperative R&D agreements with industry. ARS provides funding (via Federal pass-through contributions) to a university project for a pilot-scale nanocellulose production line that produces specialized fibers for developing a 3D wet forming process used in producing fiber-molded nanofiber laminated composite products with grease and water resistance.

USDA/NIFA priorities under PCA 2 include R&D focused on novel uses and high-value-added products of nano-biomaterials from agricultural and forest origins; nanotechnology-enabled smart sensors for accurate, reliable, and cost-effective early and rapid detection of targets of interest in agricultural production and food safety; cost-effective distributed sensing networks for intelligent and precise application of agricultural inputs; and monitoring physiological biomarkers for optimal crop or animal productivity and health. Examples of supported projects include development and evaluation of low-cost, easily deployable molecularly imprinted polymer nanoparticles for detecting agricultural viruses and toxins of concern and nanotechnology-enabled hybrid phosphorus platforms for increasing phosphorus use efficiency. This work complements SBIR funding by EPA to develop and manufacture at kilogram scale commercially viable nanoparticle-based phosphorus fertilizers, with subsequent testing of these nanofertilizers on soybean production at the multi-acre

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93 www.nasa.gov/spacetechpriorities
94 www.nasa.gov/stmd-the-nasa-innovative-advanced-concepts-niac
95 www.nasa.gov/center-innovation-fund
96 www.nasa.gov/ames-cct/eci
97 www.nasa.gov/space-tech-industry-partnerships
98 www.nasa.gov/stmd-flight-opportunities

scale. This technology promises to improve the efficiency of phosphorus use in fertilizers and reduce waste runoff from fields that can lead to harmful pollution and algae blooms.[99]

PCA 2 investments from the DOJ/National Institute of Justice (NIJ) Forensic Science Research and Development program[100] fund projects that apply nanotechnology toward the sensitive and selective detection and identification of trace chemical and biological materials collected as forensic evidence.

The Federal Highway Administration supports research in materials science that includes nanoscale measurements, modeling, and material mix design to improve the safety and performance of the Nation's transportation system. Innovative technologies and approaches for modernizing and renewing transportation infrastructure are paramount to ensuring the safety, mobility, accessibility, and economic productivity for all people traveling and receiving goods across U.S. roadways. Research and development leading to deployment of high-performance but abundant nanomaterials shows promise for improving the long-term performance and resilience of transportation pavements and structures. Topics of particular interest include investigation of supplementary cementitious materials, including nanoscale characterization of these materials and assessments of design mix and performance. FHWA is exchanging information on this subject with USDA/Forest Service, coordinating research on the use of nanocellulose as a supplementary material. It plans to extend coordination on supplementary cementitious materials to NIST and the Army Engineer Research and Development Center. FHWA is also collaborating with the Federal Aviation Administration in investigating the potential use of plastic waste in asphalt pavements. Additional plans include an initial investigation of quantum computing for nanoscale modeling of heterogeneous materials.

The U.S. Patent and Trademark Office (USPTO) provides intellectual property policy advice and guidance to the Executive Branch, grants patents on nanotechnology applications that meet the statutory requirements, works with Federal partners to identify key emerging technologies that the United States should focus on to enhance innovation, and supports an intellectual property system for all Americans, including independent inventors and entrepreneurs. USPTO has been providing information and analysis of nanotechnology patenting trends to NSET and NNCO as a way to pinpoint emerging applications and as a metric for commercialization activity. Work is ongoing to identify nanotechnology-related patent classification symbols[101] and track patenting trends in those topic areas.

Progress on Goal 3. Provide the infrastructure to sustainably support nanotechnology research, development, and deployment.

The physical equipment, digital models, simulations, and data that make up the research infrastructure are essential for all of the NNI goals. The need for often expensive, specialized tools, as well as the expertise to utilize them, remains a key requirement for much of nanotechnology R&D. One distinguishing feature of the NNI is the shared infrastructure that provides researchers and developers with access to the tools required to create, characterize, and understand nanomaterials and nanotechnology-enabled components, devices, and

[99] cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.abstractDetail/abstract_id/11544/report/0
[100] nij.ojp.gov/topics/forensics/forensic-science-research-and-development
[101] www.uspto.gov/web/patents/classification/cpc/html/cpc.html

systems. NNI participating agencies support advances in tool development, establishment and sustainment of facilities, and creation and dissemination of cyber resources. Furthermore, the NNI infrastructure is essential to enabling research in other national priorities such as QIS, AI, and microelectronics. A few selected examples of Goal 3 progress are shown below.

Nurturing the NNI research infrastructure. NSF has funded the National Nanotechnology Coordinated Infrastructure sites from 2015 through 2025, with a national coordination office added in 2016. NNCI has been providing access to facilities, tools, and expertise to advance research at the nanoscale. In addition to academic and government users, innovators have been able to quickly access the tools they need to push their ideas forward.[102] NNCI also has supported work in critical and emerging technologies. Since 2018, over a third of publications that reference using the NNCI are related to QIS and over a quarter are related to next-generation semiconductors.[103] Sites also have leveraged NSF investment to secure additional support in these priority areas. For example, the NNCI Nebraska Nanoscale Facility helped position Nebraska to participate in the "second quantum revolution" with the NSF-supported Emergent Quantum Materials and Technologies cluster.[104] As mentioned elsewhere in this report, other NSF-supported centers and initiatives such as Science and Technology Centers (STCs), ERCs, CCIs, MRSECs, Biofoundries, Materials Innovation Platforms (MIPs), Major Research Instrumentation, and Mid-Scale Research Infrastructure also play significant roles in providing infrastructure to support nanotechnology research.

NCI, in collaboration with NIST and FDA, established the Nanotechnology Characterization Laboratory (NCL) to perform comprehensive preclinical testing of nanoparticles. Serving as a national resource and knowledge base, NCL supports all cancer researchers in facilitating the regulatory-based characterization requirements of nanotechnologies intended as cancer therapies and diagnostics. Over its years of operation, NCL has characterized more than 600 different nanomaterials spanning various nanotechnologies and therapeutic loads. It has fostered more than 200 collaborations with academia, industry, and government labs, and has published over 300 peer-reviewed publications covering nanoparticle characterization, immunotoxicity, pharmacokinetics, and safety. Additionally, NCL has established nearly 100 standardized protocols for various nanoparticle assays and works alongside standards organizations to develop consensus standards for the nanotechnology community. Twenty-four collaborators of NCL have reached clinical trials with the aid of data produced at the facility, and several now have commercially marketed formulations.

NIAID contract support has played a key role in developing structure-based research platforms and services that facilitate advancements in nanoparticle immunotherapeutics and therapeutic design. These platforms include computational and bioinformatic platforms as well as structural biology platforms such as cryo-electron microscopy, x-ray crystallography, and nuclear magnetic resonance spectroscopy, alongside functional characterization. This funding has enabled the creation of nanoparticle neutralizing antibodies and therapeutics aimed at combating viruses and antimicrobial-resistant bacteria. Through the utilization of

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[102] nap.nationalacademies.org/catalog/29063/quadrennial-review-of-the-national-nanotechnology-initiative-2025-securing-us

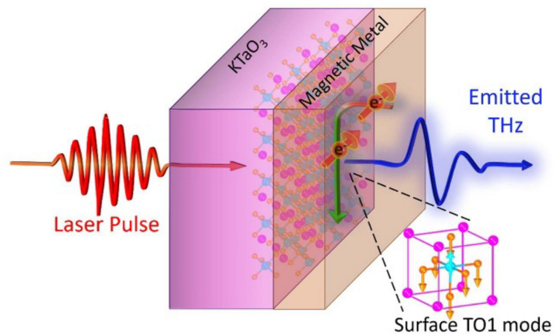
[103] nnci.net/sites/default/files/reports/NNCI%20CO%20Annual%20Report%202025%20Final%20for%20Web.pdf

[104] equate.unl.edu

these research platforms and services and various viruses and bacterial pathogens, NIAID has facilitated groundbreaking progress in the field.

Probing atomic vibrations at the quantum interface with surface-sensitive spintronic terahertz spectroscopy

The ability to probe and understand quantum dynamics of surfaces—such as surface phonon modes in quantum paraelectrics for facilitating interfacial superconductivity—is highly challenging, especially below 1 THz. The main challenges are that the interface of interest is very small (only a few nanometers thick) and that high resolution, THz-range quantum effects are difficult to capture. Researchers from Argonne National Laboratory and a university have created a surface-sensitive spintronic terahertz spectroscopy (SSTS) instrument capable of sensing the collective phonon modes only a few nanometers deep, probing surface soft transverse optical (TO1) phonon dynamics in $KTaO_3$ and $SrTiO_3$. SSTS relies on a thin magnetic film being deposited onto the oxide crystal, granting researchers the ability to probe the interface when the magnetic layer is struck with radiation. The SSTS technique opens the door for sensing other quantum behaviors that are difficult to measure, especially at interfaces, such as magnetism and superconductivity. The combination of advanced instrumentation and techniques such as SSTS is important for retaining U.S. global leadership in nanotechnology and quantum technologies.[105]



In SSTS, a laser pulse is fired at the sample from one side at the $KTaO_3$, and the THz radiation is emitted. From that radiation, the TO1 surface phonon is detected in the oxide less than 5 nm from the interface. Image credit: Z.D. Chu, ANL.[105]

Enabling advances in fundamental understanding of nanomaterials with unique instrumentation and light sources. Scientists have been using light sources and innovative instruments available only at DOE National Laboratories to develop fundamental knowledge about nanomaterials at the molecular level, which can be used to develop novel applications. For example, researchers from Oak Ridge National Laboratory (ORNL) have pioneered a novel approach toward understanding the behavior of electric charge in microelectronics and nanoscale material systems. This approach enables visualizing charge motion at the nanometer level but at speeds thousands of times faster than conventional methods, using a scanning probe microscope equipped with an automated control system that enables a unique spiral pattern for efficient scanning along with advanced computer vision techniques for data analysis. The rapid, thorough view of charge-transfer processes demonstrated in the new approach was previously unattainable.[106]

In another example, researchers from Argonne National Laboratory (ANL) and ORNL examined the changes that occur in the structure of a specific nanomaterial as it changes from conducting an electrical current to not. The material, strontium cobalt oxide, easily switches between conducting and insulating phases. The researchers used DOE's Advanced Photon Source and a technique called x-ray photon correlation spectroscopy, which can directly

[105] www.anl.gov/article/new-nanoscale-technique-unlocks-quantum-material-secrets, doi.org/10.1126/sciadv.ads8601
[106] www.ornl.gov/news/deciphering-dynamics-electric-charge, doi.org/10.1038/s41467-023-42583-x

measure how fast the material fluctuates between these two phases at the atomic scale.[107] This development has potential applications in semiconductor devices.

In a third example, ANL researchers discovered that how calcite is synthesized, or chemically transformed, can dramatically change the internal structure of individual mineral particles. The scientists compared the external shape and internal structure of calcite particles grown by two synthesis approaches using scanning electron microscopy, powder x-ray diffraction, and Bragg coherent diffraction imaging. For one synthesis approach, calcite crystals were grown slowly, and a 3D map of the crystal structure inside the calcite particles showed the expected orderly, repeating patterns. Using the other synthesis approach, crystals were grown very quickly. This time, a more complex internal structure was seen. Each perfectly shaped calcite crystal was composed of countless nanoscale crystalline fragments, or defects. The ability to identify such fragmentation in the crystalline structure of minerals may help in designing materials with optimized strength and toughness, and could be relevant to other fields such as catalysis.[108]

Plans for PCA 3. Research Infrastructure and Instrumentation

NNI participating agencies will continue to invest in the NNI research infrastructure, which provides critical support to the entire NNI ecosystem, and which is vital to other priority research areas such as microelectronics, artificial intelligence, and quantum information science. These contributions to other national priorities are highlighted in the most recent National Academies review of the NNI,[109] which recommends putting emphasis on sustaining and renewing the U.S. nanotechnology research infrastructure. As recommended by the National Academies panel, NNCO will continue its efforts to coordinate infrastructure activities across the NNI participating agencies.

PCA 3 accounts for 47% of the DOE investment, and over 57% of the NIST investment, in the 2026 NNI budget request. Key NNI infrastructure investments include the DOE NSRCs, the NSF NNCI, the NIST CNST and Boulder Microfabrication Facility, and the NIH/NCI NCL. The largest PCA 3 investment in the 2026 NNI budget request is from DOE, followed by NIST, NIH, NSF, and DOW.

The five Nanoscale Science Research Centers[110] are the core of the DOE nanotechnology research infrastructure investments. Each center has a particular focus: synthesis and characterization (Center for Functional Nanomaterials at Brookhaven National Laboratory); electronics/photonics and soft/hybrid materials assembly (Center for Integrated Nanotechnologies at Sandia National Laboratory and Los Alamos National Laboratory); interfaces, interactions, and nanoscale assembly (Center for Nanoscale Materials at Argonne National Laboratory); materials science and quantum information science (Center for Nanophase Materials Sciences at Oak Ridge National Laboratory); and soft matter synthesis/functionality and energy conversion/storage (Molecular Foundry at Lawrence Berkeley National Laboratory). The NSRCs have experienced a steady growth in use, from about 1,000 unique users per year in 2007 to over 4,500 in 2024. They are synergistic and

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[107] www.anl.gov/article/scientists-shine-new-light-on-the-future-of-nanoelectronic-devices
[108] www.anl.gov/article/not-all-calcite-crystals-are-as-perfect-as-they-appear
[109] nap.nationalacademies.org/catalog/29063/quadrennial-review-of-the-national-nanotechnology-initiative-2025-securing-us
[110] nsrcportal.sandia.gov. See links to individual NSRC websites on this page.

coordinated with other DOE scientific user facilities and research centers across the Nation that offer cutting-edge instrumentation and highly trained staff scientists (e.g., the Microelectronics Science Research Centers and National Quantum Information Science Research Centers). All of the DOE user facilities are available through a competitive peer-reviewed proposal process.

Beginning in 2024, and with completion scheduled for early 2026, DOE has been executing an NSRC recapitalization effort that involves acquiring and installing 17 new instruments across the network of NSRCs, including advanced microscopes, lithography and deposition equipment, robotics and multimodal tools, novel sample environments, and time-resolved tools. These upgrades complement additional recapitalization efforts at other DOE National Laboratory facilities, many of which are collocated with the NSRCs, including a new storage ring at the Advanced Photon Source Upgrade (ANL); the Proton Power Upgrade at Spallation Neutron Source (ORNL); the Linac Coherent Light Source—II—High Energy (SLAC National Accelerator Laboratory); the Advanced Light Source Upgrade (Lawrence Berkeley National Laboratory); and the National Synchrotron Light Source II Experimental Tools III (NEXT-III) Project. All of these activities are informed by the May 2024 DOE Basic Energy Sciences Advisory Committee (BESAC) report, *New and Upgraded National User Facilities in Basic Energy Sciences*[111] and the recommendations of the April 2024 BESAC report on the NSRCs.[112]

NIST is sustaining its PCA 3 research infrastructure investments at the Center for Nanoscale Science and Technology[113] and Center for Neutron Research (NCNR)[114] user facilities on the NIST Gaithersburg campus, the NIST Boulder Microfabrication Facility, and NIST capabilities at the National Synchrotron Light Source II (NSLS-II).[115] NIST's CNST is a nanofabrication facility within the Physical Measurement Laboratory where public- and private-sector researchers can have access to commercial nanoscale measurement and fabrication tools and methods, along with associated technical expertise. The facility consists of approximately 60,000 ft^2 of laboratory space and approximately 19,000 ft^2 of cleanroom space, including over 100 commercial tools in lithography, focused ion beam nanofabrication and characterization, advanced imaging and analysis, sample and substrate preparation, metrology, thin-film deposition and processing, dry-etch equipment, and wet-lab capabilities.[116] CNST provides important contributions to NIST's support for semiconductor and microelectronics R&D, and complements additional NIST nanotechnology-related infrastructure investments funded under the CHIPS and Science Act. NCNR is conducting an extensive repair, maintenance, and upgrade project that is expected to be complete in 2026. NIST's Synchrotron Science Group, stationed at the NSLS-II facility at Brookhaven National Laboratory, develops state-of-the-art synchrotron x-ray measurement technology around a core competency in x-ray absorbance spectroscopy.

NIH/NCI continues its support for the Nanotechnology Characterization Laboratory, which specializes in characterizing nanomaterial formulations for imaging and therapeutic applications developed by researchers spanning academia, industry, and government sectors. Through its Assay Cascade program—which assesses physicochemical, immunology,

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111 science.osti.gov/-/media/bes/besac/pdf/Reports/Report-to-BESAC-on-New-and-Upgraded-National-User-Facilities-2024-05-28Final.pdf
112 science.osti.gov/-/media/bes/besac/pdf/Reports/BESAC-NSRC-Subcommittee-Report-20240405-watermark.pdf
113 www.nist.gov/cnst
114 www.nist.gov/ncnr
115 www.nist.gov/mml/mmsd/synchrotron-science-group
116 www.nist.gov/cnst/equipment

pharmacology, and toxicology properties—NCL receives a wide array of nanomedicine technologies and has experience with virtually all nanoparticle platforms, therapeutic agents, and applications aimed at advancing cancer diagnostics and treatments. NCL has expanded its focus to include the evaluation of nanomedicine bioequivalence, as well as the assessment of personalized vaccine strategies and immunotherapies. NIH/NEI supports university research core facilities nationwide that provide shared resources, technical expertise, and advanced instrumentation to accelerate progress in nanotechnology and novel therapeutic approaches.

Under PCA 3, NSF supports STCs, ERCs, CCIs, MRSECs, MIPs, Biofoundries,[117] Major Research Instrumentation,[118] and Mid-Scale Research Infrastructure[119] projects, many of which explore or enable novel nanoscience and nanotechnology research and concepts. The 2026 budget request includes support for user facilities and networks, acquisition of major instrumentation, and other activities that enhance the Nation's physical infrastructure for nanotechnology research, as well as research on tools to advance nanotechnology research and commercialization, including next-generation instrumentation for characterization, measurement, synthesis, and design of materials, structures, devices, and systems, all of which NSF will continue to support. Examples include the Center for Cellular Construction,[120] supported by the Directorate for Biological Sciences, a nanosystems ERC on cell technology,[121] and a CCI that investigates the fundamental molecular mechanisms by which nanoparticles interact with biological systems.[122] NSF invested in five new Biofoundries in 2024, committing to developing new high-throughput infrastructure to design and build biological systems at the nanoscale. The Major Research Instrumentation program serves to increase access to multiuser scientific and engineering instrumentation, including instrumentation needed for NSE activities.

NSF funding for the NNCI[123] user facilities and the NNCI coordination office continued through 2025. NSF has issued a solicitation in 2026 to develop a successor network to NNCI, the National Quantum and Nanotechnology Infrastructure (NQNI), to continue its support for infrastructure critical to nanoscience and engineering, as well as advanced quantum information engineering and technologies.[124] NQNI will accelerate U.S. leadership in quantum information science and engineering, nanotechnology, semiconductors, biotechnology, advanced manufacturing, and other emerging technologies. In addition, in 2024 NSF established the National Quantum Nanofab (NQN),[125] which is developing advanced nanofabrication approaches required to build, control, and connect quantum devices with their supporting infrastructure. With the goal of transitioning quantum discoveries into functioning quantum devices, the NQN serves as an open-access national facility for academic, government, and industrial users.

DOW support for nanotechnology research infrastructure includes the Institute for Nanoscience at the Naval Research Laboratory and the AFRL Materials Solutions Network at CHESS. NRL maintains research facilities at Stennis, MS; Key West, FL; Monterey, CA; and

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117 www.nsf.gov/funding/opportunities/biofoundries-biofoundries-enable-access-infrastructure-resources/506172/nsf23-585
118 www.nsf.gov/funding/opportunities/mri-major-research-instrumentation-program
119 www.nsf.gov/funding/opportunities/mid-scale-ri-1-mid-scale-research-infrastructure-1
120 www.nsf.gov/funding/opportunities/ccc-center-cellular-construction/505609/157049
121 www.nsf.gov/awardsearch/showAward?AWD_ID=1647837
122 www.nsf.gov/awardsearch/showAward?AWD_ID=2001611
123 nnci.net
124 www.nsf.gov/funding/opportunities/nqni-national-quantum-nanotechnology-infrastructure
125 www.nsf.gov/awardsearch/showAward?AWD_ID=2330067

Washington, DC, where the Institute for Nanoscience is located. The Institute for Nanoscience and its companion, the Institute for Quantum Science, support DOW fundamental and applied nanotechnology research. Facilities at the Institute for Nanoscience include a 5,000 ft^2 class 100 clean room; ultra-quiet environmentally controlled lab modules; electron-beam, optical, direct-write, and 3D lithography systems; multiple deposition, etch, and ion mill systems; a plasma-enhanced atomic layer deposition system; and scanning electron, scanning tunneling, and atomic force microscopes.

The Army Institute for Soldier Nanotechnology is undergoing a number of equipment upgrades at its facilities, including a spectral cathodoluminescence detector system being added to an existing field emission scanning electron microscope, an imaging spectroscopic ellipsometer, a confocal Raman microscope with a UV laser light source and the latest advances in Raman microscopy, a new high-performance atomic force microscope (AFM) including fast high-resolution AFM imaging and high-precision nanomechanical measurement capabilities, and a dynamic mechanical analyzer used to characterize the mechanical and viscoelastic properties of materials.

FDA's NCTR Nanocore is upgrading its instrumentation and infrastructure to address emerging measurement challenges such as microplastics and nanoplastics. It houses high-resolution scanning and transmission electron microscopes and a low-voltage electron microscope to elucidate biological structures and characterize nanomaterials. FDA/CBER recently acquired a 100 keV cryo-electron microscope, which can characterize size and uniformity of LNPs as well as determine atomic-level features of protein nanoparticles or recombinantly expressed proteins that are included in vaccines or used as reagents that assay properties of vaccines.

Progress on Goal 4. Engage the public and expand the nanotechnology workforce.

Nanotechnology innovation relies on STEM talent and a highly skilled workforce. Thousands of students are trained every year in NNI-supported nanotechnology user facilities and research centers. There are also targeted curriculum-development efforts and internship programs, and NNI-funded research centers partner with community colleges to promote training of the technical workforce. NNCO works with NNI participating agencies, university-based student groups, and teachers organizations to conduct public outreach and help inspire students to learn about nanotechnology and to pursue STEM careers. Just a few examples of NNI progress in Goal 4 are featured below.

Leveraging cutting-edge research to train the next generation of scientists. NSF supports the education of students in nanotechnology by supporting cutting-edge research projects that provide opportunities for the students to work on the research projects. For example, Research Experiences for Undergraduates (REU) awards have enabled students to participate in nanoscience and engineering research. Participants engage in research in a range of areas including optics, chemistry, and electronics, and develop their network as well as technical skills in the area. In addition to conducting laboratory research, students have access to advanced instruments and facilities. A structured training series, weekly seminars, and a tiered mentoring approach promote collegial and mentoring relationships among students, mentors (graduate students and post-docs), and faculty. In another example, the NSF Nanosystems ERC for Nanotechnology Enabled Water Treatment has offered programs for high school teachers and students, and for undergraduate and graduate students. From semester-long courses to summer research experiences, students have been able to engage with a multidisciplinary group of scientists dedicated to the development of sustainable nanotechnology-enabled solutions to provide water access around the globe. Under the Research Experiences for Teachers (RET) program, another university has provided STEM teachers with research-based professional development and training in nanotechnology. This six-week summer program enhances teaching through inquiry-based methods, helping educators integrate numerous STEM concepts across multiple disciplines and inspire student interest in STEM careers. Participants gain hands-on laboratory experience, develop teaching modules aligned with state and national standards, and earn graduate credits.

Nurturing undergraduate interest in STEM and nanotechnology. NIH/NIEHS, through the Academic Research Enhancement Award (AREA) program for undergraduate-focused institutions,[126] supports the development of research skills and scientific interest in undergraduate students, encouraging them to pursue graduate degrees or careers in STEM. These awards provide students with hands-on experience in interdisciplinary environmental science and engineering, with several projects focusing on nanotoxicology. One currently active award is investigating the role of environmental weathering and gastrointestinal digestion on the bioavailability and toxicity of microplastic and cadmium mixtures. Another project is conducting a meta-transcriptomic assessment of chronic respiratory exposure to cobalt-based nanomaterials using a microfluidic 3D lung model to evaluate potential predisposition to lung injury.

Creating opportunities for the next generation of nanotechnology students and faculty. NIFA has been providing opportunities through nanotechnology R&D and education to support the development of workforce for the growing research fields at the nanotechnology-agriculture-food nexus. Postdoctoral fellowships provided through the AFRI Education and Workforce development program are designed to be transferable across institutions, so recipients can apply for and begin faculty positions with their own funding sources. In 2024, two prior awardees started new faculty positions and successfully began their independent research careers. The NIFA-supported 2024 Nanoscale Science and Engineering for Agriculture and Food Systems Gordon Research Conference included student participation and student-led sessions. Lastly, a university faculty member was recognized with a distinguished faculty lectureship for sustained excellence in teaching, scholarship, and service. The public lecture focused on nanotechnology innovations for shared sustainability, including research supported by NIFA and NSF examining nanotechnology-enabled phosphorus use efficiency for sustainable agriculture practices.

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[126] grants.nih.gov/funding/activity-codes/R15

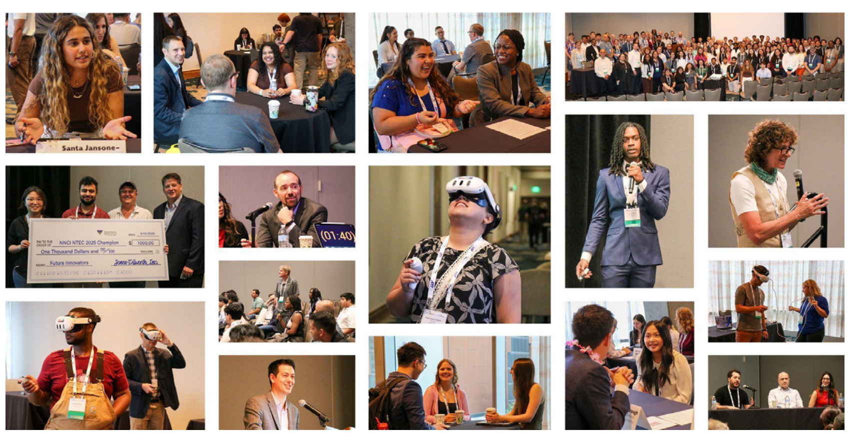
NextTech Student Network and The Student Leaders Conference

NNCO facilitates the NextTech Student Network,[127] which consists of undergraduate student-run clubs across the country that share a passion for nanotechnology and emerging technologies. Since 2016, the network has been sharing resources and professional development opportunities—and has been organizing the annual Student Leaders Conference (SLC). Historically, the SLC has been co-located with a major technology conference and the annual SBIR/STTR Spring Innovation Conferences. In 2024 and 2025, the NSF-funded Micro Nano Technology Education Center[128] supported student travel, which significantly increased attendance from community college students. Due to this funding and collaborative efforts with NNCO and others, the 2025 SLC was attended by almost 200 students along with community college professors and industry participants.

The theme of the 2025 event was "Micro Nano Electronics and Photonics Workforce Development." The event was kicked off by a keynote presentation from a semiconductor company, followed by a session introducing the fields to the students. Then a student organizer provided guidance and best practices for students attending a conference for the first time, and the students participated in one of two speed networking sessions with industry and/or academic representatives. Concurrently, students joined one of two career pathways panels, which were moderated by student organizers.

On the second day, students were invited to a networking breakfast with industry professionals. The students then participated in a future innovators panel and a student/postdoc pitch contest. These two events were part of NNCI's Nanotechnology Entrepreneurship Challenge (NTEC). First, the students heard from a panel composed of representatives from different stages in the entrepreneurship ecosystem. Then the NTEC finalists pitched their innovative ideas to the panelists as part of a competition for start-up funding. The winning team developed a metal organic framework system to remove PFAS. Team members received access and an R&D budget from NNCI and a monetary award from a private company. Students also participated in a career awareness fair and presented their research at the poster session.

During the last day of the conference, students and educators discussed microelectronics research and development, innovative ways to teach students about semiconductors, and a student-led project to develop digital twins for training and educational opportunities. The conference ended with a virtual-reality demonstration in which participating companies, institutions, and student groups showcased virtual-reality educational tools. These tools help train and upskill students and workers without the need to access a clean room or expensive equipment.



Participants in the 2025 SLC. Image credits: TechConnect.

[127] nexttechnetwork.org
[128] micronanoeducation.org

Plans for PCA 4. Education and Workforce Development

Many NNI R&D and infrastructure programs support education and workforce development, therefore even agencies that do not report funding to PCA 4 are contributing to the NNI's education and workforce development efforts. NSF accounts for the largest amount of NNI funding reported to PCA 4, followed by NIH and NIFA. A sampling of current and planned NNI agency activities related to PCA 4 is summarized below.

NSF supports education and workforce development activities in all areas of nanoscale science and engineering, including engagement with the public. Typical activities supported include graduate and post-doctoral fellowships, high school and undergraduate student supplements, single-investigator projects, team grants, and multi-institutional center awards. The Directorate for STEM Education also addresses priority areas within educational research and in the NSF STEM K-12 Program,[129] which is aimed at moving knowledge gained from fundamental learning and educational research to applications in pre-K–12 STEM classrooms, as well as using knowledge from practice to drive fundamental research.

Future plans for education and training programs at NSF include continued support for the following programs: Research Experiences for Undergraduates,[130] which will increase nanotechnology-related awards to ensure that undergraduates are encouraged to pursue careers and graduate studies in STEM research; Research Experiences for Teachers,[131] in which K-14 educators enhance curricula and pedagogy in STEM through fostering of collaborations with university researchers and industry; ERCs and IUCRCs, which grow the workforce through education and workforce development programs in active nanotechnology-related centers; and engineering education research, which will continue building the knowledge base needed to more effectively educate the next generation of engineers in nanotechnology-related fields. MRSECs, CCIs and STCs are all required to provide workforce development beyond graduate student training as well. NSF collaborations with other agencies related to PCA 4 include the Research Internships for Graduate Students at AFRL Supplemental Funding Opportunity.[132]

NIH supports early-career scientists and strengthens the biomedical research workforce through training programs and fellowships, with some of these initiatives incorporating nanotechnology. The SuRE (R16) and AREA (R15) grants provide structural support for faculty and undergraduate institutions with limited funding and smaller research portfolios, allowing them to pursue pilot research projects.[133] Many of these projects apply nanotechnology to a wide variety of biomedical challenges, including targeted drug delivery, tumor imaging, neurotoxicity, and antibiotic resistance. NIBIB also funds fellowships like the F30 to support dual-degree predoctoral students (e.g., MD/PhD, DO/PhD, DDS/PhD, DVM/PhD) by enhancing integrated research and clinical training to prepare them for careers as physician- or clinician-scientists.[134] One F30-supported university project is developing a novel MRI contrast agent using europium encapsulated in perfluorocarbon nanoemulsions, enhancing imaging of low-oxygen tumor regions.[135] NEI-supported research actively involves

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129 www.nsf.gov/funding/opportunities/stem-k-12-nsf-stem-k-12
130 www.nsf.gov/funding/initiatives/reu
131 www.nsf.gov/funding/opportunities/research-experiences-teachers-engineering-computer-science
132 www.nsf.gov/funding/opportunities/dcl-research-internships-graduate-students-air-force-research
133 grants.nih.gov/grants/guide/pa-files/PAR-24-145.html, grants.nih.gov/grants/guide/pa-files/PAR-25-134.html
134 grants.nih.gov/grants/guide/pa-files/PA-23-261.html
135 pmc.ncbi.nlm.nih.gov/articles/PMC10440236/

undergraduate students in utilizing nanotechnology tools to create more effective, dose-controllable drug delivery implants, thereby encouraging a wide range of early-stage students to pursue careers in the field of nanotechnology.

A key USDA/NIFA program that supports nanotechnology education and workforce development is the AFRI Education and Workforce Development program,[136] which includes program areas on professional development for agricultural literacy; agricultural workforce training at community colleges; food and agricultural non-formal education, research and extension experiences for undergraduates; and predoctoral and postdoctoral fellowships. Examples of nanotechnology projects funded under this program include research on plant virus nanoparticle technology for plant vaccines and on plant-derived nanovesicles for nucleic acid delivery for control of microbial pathogens. NIFA-supported researchers participate in NNI public webinars that provide educational content for both the research community and the general public. NIFA supports the bi-annual Gordon Research Conference on Nanoscale Science and Engineering for Agriculture and Food Systems,[137] which plays an educational role in disseminating and exchanging information on nanotechnology applications for sustainable food production. NIFA also supports a range of other webinars and symposia promoting nanotechnology research and technology. For example, project director meetings provide networking among the NIFA nanotechnology awardees, enabling NIFA program staff to check project progress across the portfolio and to enlist stakeholder input that contributes to the development of national priorities for nanotechnology at NIFA.

Progress on Goal 5. Ensure the responsible development of nanotechnology.

The responsible development of nanotechnology has been an integral part and goal of the NNI since its inception. This includes long-standing considerations such as understanding ethical, legal, and other social implications (ELSI) and nanotechnology-related environmental, health, and safety (nanoEHS) implications of nanotechnology development and the responsible conduct of research. These efforts support the other NNI goals by fostering public confidence and regulatory certainty, which speeds laboratory discoveries to market. Just a few examples of these efforts are illustrated below.

Coordinating nanoEHS databases across agencies and making data accessible. Many of the agencies participating in the NEHI Working Group coordinate on nanoEHS database and informatics efforts through an informal interagency interest group, which has facilitated sharing information among NNI agencies. Agency participants seek to maximize the utility of Federal nanoEHS data through the promotion of FAIR (Findable, Accessible, Interoperable, Re-usable) data standards, and the development of tools that (semi) automate the creation of interoperable file formats. EPA has been working with other participating agencies to make publicly available its Nanomaterials Knowledgebase (NaKnowBase), which contains data from a full list of materials obtained from published EPA research relevant to the potential environmental and biological actions of engineered nanomaterials.[138] Agencies are also working together with NNCO to use EPA's ontology mapping application (OntoSearcher) to enable virtual integration of nanoEHS data developed by (or with support from) other NNI

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[136] www.nifa.usda.gov/grants/funding-opportunities/agriculture-food-research-initiative-education-workforce-development
[137] www.grc.org/nanoscale-science-and-engineering-for-agriculture-and-food-systems-conference
[138] comptox.epa.gov/dashboard/chemical-lists/naknowbase

participating agencies with NaKnowBase. NNCO secured interns through the Virtual Student Federal Service (2023–2025) to assist in developing and testing the OntoSearcher app. Recent publications document the progress of these efforts.[139]

Understanding exposures to and potential risks of micro-/nanoplastics. NIH/NIEHS funded research using cutting-edge tools to assess micro- and nanoplastics accumulation in the human body. These studies evaluated accumulation of MNPs in the brain compared to other organs, and assessed potential neurological impacts of long-term exposure. The research sets the stage for future investigations into the role of nanoplastics in neurotoxicity and neurodegenerative disease progression. It also highlights the need to continue developing standardized methods for detecting and measuring MNPs in complex biological tissue matrices.[140]

FDA scientists have been involved in several complementary research projects related to MNPs. FDA's National Center for Toxicological Research published important work that facilitates development of a mass spectrometric and spectroscopic database to assist with identification, classification, and quantification of MNPs in relevant environments.[141] Scientists from the FDA Human Foods Program and NCTR published a regulatory science perspective on the analysis of microplastics and nanoplastics in human food, based on a comprehensive literature review.[142] The FDA's Center for Veterinary Medicine recently completed a research project to understand contamination of animal (pet) food with MNPs from food waste recycling processes, specifically the generation of microplastics during mechanical depacking. The research is crucial for assessing exposure, understanding environmental impacts, informing regulations, and improving technology in the field of food waste recycling for animal food production. By quantifying and characterizing microplastic residues, the study helps identify potential risks to animal and human health through the food chain.

The National Center for Environmental Health (NCEH) and the Agency for Toxic Substances and Disease Registry (ATSDR) have been engaged in a complementary project to systematically review data available in the scientific literature to assess if there is sufficient evidence to determine the potential routes of human exposure to MNPs in freshwater, the pathways MNPs follow to reach freshwater systems and drinking water (i.e., to enable the design of preventive measures), and data needed to better understand human exposure and potential health effects. From over 6,000 papers reviewed, 253 were selected for quality assessment, leading to a further down-selection of 105 papers for data extraction and analysis. Findings revealed that a variety of sampling and characterization methods were used in these studies, which led to a conclusion that there is a need for developing standard methods to ensure test reliability for quantifying MNPs and for physically and chemically characterizing them.[143]

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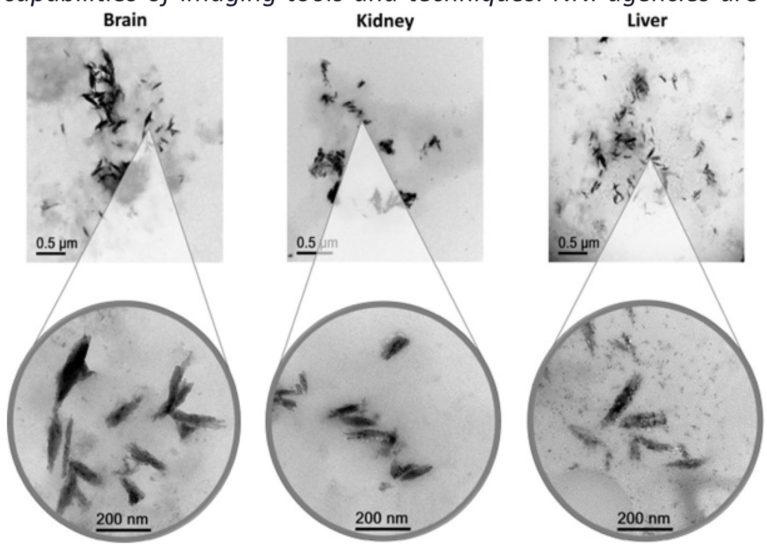
139 doi.org/10.12688/f1000research.141056.1, doi.org/10.1016/j.comtox.2024.100316, doi.org/10.1039/D3EN00619K
140 pubmed.ncbi.nlm.nih.gov/39901044
141 doi.org/10.1016/j.impact.2023.100467
142 doi.org/10.1021/acs.analchem.3c05408
143 doi.org/10.3390/microplastics4030060

Extending the nanoEHS infrastructure to address emerging priorities: Deciphering the environmental and health effects of micro- and nanoplastics

Studying the complex interactions of engineered nanomaterials in the environment and in living organisms required the development of special tools and methods. These tools and analytical techniques can be applied to study incidental nanomaterials such as micro- and nanoplastics. Microscopy and spectroscopy tools that were used to characterize engineered nanomaterials in health and safety studies are being adapted for studies on micro- and nanoplastics. For example, atomic force microscopy, a type of scanning probe microscopy used extensively in EHS assessments of engineered nanomaterials, is being combined with other techniques to measure important nanoplastic parameters such as stiffness and deformation.[144]

NNI support over two decades has been critical to fostering and sustaining the nanoEHS infrastructure, which serves as the foundation for current research on micro- and nanoplastics. For example, the early recognition of the importance of evaluating real-world exposure to engineered nanomaterials spurred advances in resolution, accuracy, and capabilities of imaging tools and techniques. NNI agencies are applying these tools, methods, and protocols to understand the characteristics, fate, and impact of micro- and nanoscale fragments of plastics released into the environment and the food supply, resulting in potential human exposures.

For example, National Institute for Occupational Safety and Health (NIOSH) researchers have adapted methods developed to characterize carbon nanotubes to identify and characterize nanoplastic samples extracted from human tissue.[145] *The extracted material was visualized by transmission electron microscopy using a modification of previously established methods for generating singlet carbon nanotubes and carbon nanofibers.*[146]



Representative high resolution transmission electron microscopy imaging of nanoplastic particles isolated from human brain (frontal cortex), kidney (piece containing renal cortex and medulla), and liver (right central parenchyma). Image credits: A.D. Erdeley, NIOSH.[145]

Assuring the safety of nanoscale pharmaceutical ingredients. FDA/NCTR scientists conducted research in collaboration with CDER on risks associated with the biophysical changes of complex drug nanocrystals in the active pharmaceutical ingredient (API) due to their nanoscale dimensions. A drug that is used in the treatment of asthma was used as a model system. Noncompartmental pharmacokinetic analysis revealed higher plasma levels of this drug in female rats compared to male rats across all evaluated forms: the API alone, a physical mixture (API with excipients), and a nanocrystal formulation of the drug. These findings were published[147] and demonstrate significant sex-based differences in the

[144] doi.org/10.1021/acs.est.4c12170
[145] doi.org/10.21203/rs.3.rs-6166886/v1
[146] doi.org/10.1186/s12989-020-00392-w
[147] doi.org/10.1016/j.ijpx.2024.100254, doi.org/10.2147/IJN.S494224

pharmacokinetics of this drug in the rat model. The study highlights the importance of evaluating sex differences during preclinical drug development to support precision dosing strategies that ensure equivalent efficacy and safety outcomes in male and female patients.

Understanding the environmental impacts and public perception of nanotechnology used in food and agriculture. NIFA-supported researchers have been studying the fate and interaction of zein (corn-derived protein) nanoparticles (ZNPs) with crop plants and insects. Understanding these effects will be critical for safe applications of ZNPs to increase yield, minimize environmental impacts of pesticides, and increase overall efficiency in agroindustry. Another team of NIFA-supported researchers has been assessing the implications of genetic engineering and nanotechnology used in food and agriculture (agrifood), identifying strategies to ensure sustainable outcomes according to stakeholder perspectives. The project has had three primary objectives: improve decisions about these agrifoods through benefit-risk evaluations; identify strategies to ensure acceptance for these agrifoods through stakeholder engagement; and develop interdisciplinary education and training opportunities to better evaluate implications of novel agrifood technologies. Key project outcomes include information on benefit-risk evaluations of agrifoods enabled by nanotechnology that can be easily communicated to stakeholders.

Protecting workers and consumers from the potential hazards of incidental nanomaterials. The NIOSH Nanotechnology Research Center[148] continued its field studies by collaborating with the U.S. Army Corps of Engineers to assess occupational exposures to large-scale 3D printer emissions during the use of acrylonitrile butadiene styrene (ABS) and metal filaments as well as determining the effectiveness of existing engineering controls. NIOSH publications, summarized in NIOSH's technical report, *Approaches to Safe 3D Printing,*[149] include toxicology studies on the potential hazards of printer emissions. In addition to field studies, NIOSH characterized micro- and nanoplastics that accumulated in human tissues,[150] assessed the toxicity of nanoclays,[151] and used the NIOSH Occupational Exposure Banding Process to develop an exposure band to protect workers from graphene exposures until a formal exposure limit can be developed.[152]

The Consumer Product Safety Commission (CPSC), NIST, and EPA also have commissioned or conducted studies on 3D printer emissions, which may contain nanomaterials including nanoplastics. CPSC commissioned four technical reports on 3D printer emission characterization (from NIST) and toxic effects of these emissions (from NIOSH). The studies focused on characterizing components of 3D printer emissions, factors that impact emissions (e.g., manufacturer, filament type, printer type), quantifying the emissions, and assessing emission hazards.

Publications by EPA on its 3D printer studies include investigating the presence of environmentally persistent free radicals (EPFRs) on total particulate matter (TPM) released from 3D printers using ABS filaments.[153] Differences were seen between filament types as measured by electron paramagnetic resonance spectroscopy. EPA researchers hypothesized that metal content and composition of the filaments contribute not only to the type and

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[148] www.cdc.gov/niosh/centers/nanotechnology.html
[149] www.cdc.gov/niosh/docs/2024-103/default.html
[150] doi.org/10.21203/rs.3.rs-6166886/v1
[151] doi.org/10.1186/s12989-024-00577-7
[152] doi.org/10.1080/15459624.2024.2420998
[153] doi.org/10.1016/j.cej.2023.148158

number of EPFRs on TPM, but also impact the overall yield of TPM emissions and lifetime of the EPFRs. EPA assessed four different methods to identify the most complete and repeatable extraction practices, determined that high-pressure, high-temperature modified microwave digestion was the most robust technique for inorganic element extraction,[154] and highlighted potential elements of concern for respiratory risk (e.g., Si, Al, Ti, Cu, Zn, and Sn). Similar to recommendations made in the NIOSH guide on approaches to safe 3D printing, EPA's studies suggested that wearing gloves and washing hands may adequately reduce metal exposure risks for brittle feedstock such as metal-fill thermoplastics. In addition, general safety practices should be employed to minimize exposure, such as keeping 3D printers in well-ventilated spaces or in protective cabinets, as well as avoiding spending many consecutive hours near an active printer.

Another emerging incidental nanomaterial contaminant of potential concern is smoke from wildfires. NIH has supported university research to characterize the physicochemical properties and radiative effects of wildfire particulate matter reaching the metropolitan areas of New Jersey/New York during the 2023 wildfire season. The research team found mass and number concentrations of brown carbon nanoparticles in the atmosphere on days of peak smoke exposure substantially higher than those obtained in the absence of wildfire smoke. The smoke also had a cooling effect on air near the ground, potentially reducing the urban heat island effect and thus natural ventilation processes. This may result in increased residence time of wildfire particulate matter near ground level, increasing the ground-level concentrations of air pollutants from other sources.[155]

Tools and methods developed for studying engineered nanomaterials are now being used in critical applications for quantifying and understanding potential effects of incidental nanomaterials such as wildfire smoke, nanoplastics, and 3D printer emissions (as discussed in the sidebar above, p. 44).

Plans for PCA 5. Responsible Development

While PCA 5 investments comprise a small portion of the overall NNI investments, they are critical to maintaining public confidence in the safety and effectiveness of nanotechnology-enabled applications supported under other PCAs, to establishing regulatory clarity for companies seeking to commercialize nanotechnology products, and to assuring that the benefits of the NNI's nanotechnology investments accrue to all Americans. Many of these investments are also in support of the Administration's Make America Healthy Again agenda, including research on micro-/nanoplastics, PFAS detection and abatement, and nanopesticides for precision agriculture.[156]

The NNI participating agencies with dedicated funding in PCA 5 (in order of amount of funding requested for 2026) are NIH, followed by NSF, EPA, and FDA (see Table 4 on p. 6 for details).

Research on incidental nanomaterials of particular potential environmental and human health concern (e.g., micro- and nanoplastics, 3D printer and wildfire emissions) is an area of emphasis in NNI nanoEHS investments for 2025–2026. Agency activities in these areas are

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[154] doi.org/10.1007/s42452-022-05221-7
[155] doi.org/10.1038/s43247-025-02214-3
[156] www.whitehouse.gov/wp-content/uploads/2025/05/MAHA-Report-The-White-House.pdf, www.whitehouse.gov/wp-content/uploads/2025/09/The-MAHA-Strategy-WH.pdf

coordinated by informal interagency interest groups, with support from NNCO. NNCO also supports the U.S.-EU nanoEHS Communities of Research (CORs),[157] which provide a platform for scientists in Europe, the United States, and other regions of the world to collaboratively identify and address key research needs through community-led activities such as telecons, webinars, publications, and annual in-person meetings. There are currently seven CORs addressing questions about the potential EHS implications of nanomaterials; work is being done to expand this effort, particularly beyond the EU. Each COR has one U.S.-based co-chair and one EU-based co-chair. The CORs hold an annual workshop, at locations typically rotating between the United States and the European Union; the most recent workshop took place in October 2024, in Switzerland.[158]

NNCO continues to support participants in the informal databases and informatics interest group in building collaborations with other communities and related disciplines. These efforts include facilitating the efforts of participating agencies to explore AI-driven applications for nanoEHS data. NNCO is facilitating discussions between Federal nanoEHS and AI expert communities. This cross-disciplinary collaboration could identify new ways to leverage existing data and accelerate safe materials discovery, design, and enhanced risk assessment.

NIH's National Institute of Environmental Health Sciences is supporting research focused on exposure to and the health effects of micro- and nanoplastics. Within the NIH/NIEHS Intramural Division of Translational Toxicology (DTT), planned activities include completing the analysis and reporting of studies evaluating the chronic carcinogenicity of multiwalled carbon nanotubes. In addition, DTT is developing robust analytical approaches for the characterization and quantification of nanoplastics in both environmental and biological samples. These efforts aim to facilitate the proper planning of future studies assessing the potential human health impacts of nanoplastic exposure, thereby supporting the responsible development of nanotechnology.

NSF support for nanoEHS research is primarily directed at understanding nano-bio phenomena and processes; environmental, health, and societal implications and methods for reducing the risks of nanotechnology development; and sustainable development, use and end-of-life of nanomaterials. For example, the Nanoscale Interactions program[159] in NSF's Directorate for Engineering supports research to advance fundamental and quantitative understanding of the interactions of nanomaterials and nanosystems with biological and environmental media. Examples of nanoEHS-related awards that have been funded from this core program include assessment of the human health and environmental impacts of emitted nanoparticles and inhalable fly ash from Los Angeles wildfires, assessment of the environmental interactions of cyclodextrin-based nanopesticides, and understanding nanoplastic uptake in algae cells, as a step towards understanding how nanoplastics accumulate in the environment, and possible subsequent human exposures. NSF support for the Center for Sustainable Nanotechnology at a public land-grant university continued through the end of calendar year 2025.[160] Multiple NSF directorates support its Dear Colleague Letter on Critical Aspects of Sustainability: Micro- and Nanoplastics.[161] NSF also invests in nanotechnology-based efforts to mitigate harm stemming from natural disasters such as wildfires.

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[157] us-eu.org
[158] us-eu.org/eu-u-s-nanoehs-communities-of-research-workshop-oct-16-2024/
[159] www.nsf.gov/funding/opportunities/nanoscale-interactions
[160] www.nsf.gov/awardsearch/showAward?AWD_ID=2001611
[161] www.nsf.gov/pubs/2020/nsf20050/nsf20050.jsp?WT.mc_id=USNSF_25&WT.mc_ev=click

The new EPA Office of Applied Science and Environmental Solutions (OASES) is currently developing its future research plans. EPA's engagement in nanotechnology spans both the research and regulatory domains. EPA's past research has been related to the chemical safety of engineered nanomaterials, focused on developing, collating, mining, and applying data to inform both exposure and hazard assessments and support risk-based decisions related to the agency's implementation of the Toxic Substances Control Act (TSCA) and the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). EPA has also been working to reduce the volume of trash, including microplastics, entering U.S. waters by collaborating with partners to implement solutions to land-based sources of trash. Additionally, research conducted by EPA is used broadly by multiple stakeholders.

In support of FDA's mission to protect and promote public health and to help foster the responsible development of nanotechnology, it invests in research to develop models for safety and efficacy assessment, as well as to study the behavior of nanomaterials in biological systems and their effects on both human and animal health. Other FDA investments described in the PCA 1 and 2 sections of this report also support FDA's PCA 5 activities.

Several other NNI participating agencies that do not report funding specifically to PCA 5 also make important contributions to the NNI nanoEHS enterprise. For example, agencies that have been contributing to nanoEHS research within the Centers for Disease Control (CDC) include NIOSH, ATSDR, and NCEH. NIST, NIFA, DOW, and the U.S. Geological Survey (USGS) have also had relevant activities. CPSC has been supporting research to determine whether nanotechnology-enabled consumer products are hazardous to consumers, engaging with Federal partners and contractors in projects to characterize and quantify exposures to engineered nanomaterials released from products, develop methods and frameworks to assess such releases, and develop toxicity databases from published literature.[162] CPSC staff and partners are engaged in voluntary standards activities to create validated methods for quantifying and characterizing exposures from products, including an ISO project evaluating the release of nanomaterials from treated wood.

[162] See Goal 5 section above for a discussion of CPSC's work with other agencies on 3D printer emissions.

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