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# Quadrennial Review of the National Nanotechnology Initiative

*Securing U.S. Leadership Through Renewed and  
Expanded Infrastructure*

*Vicki L. Colvin, Chair*

*Catherine J. Murphy, Vice Chair*

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REPORT BRIEFING

# Why Nanotechnology R&D Infrastructure is Important

While federal investment in this area 20 years ago was driven by nanotechnology's intellectual novelty and technological promise, **realization of the economic, societal, and national security benefits are just beginning.**

**NNI and its associated infrastructure have expanded** to include a wide range of material systems fabrication and characterization tools and **its capabilities support new applications of nanotechnology in emerging use cases.**

***This quadrennial review describes a new focus for the NNI on renewing and expanding the instruments, equipment, facilities, and workforce central for converting intellectual capital to economic, social, and national security gains for the United States.***



# Nano R&D Infrastructure *ENABLES* ...

Examples of Nano R&D Infrastructure and tools

Nanoscale Sensors



**Artificial Intelligence and Deep Learning**



Medicine  
Robotics  
Sensory Technology  
Semiconductors

Foundational Fabrication and Characterization Tools



**Quantum Information and Enabling Technologies**



New Approaches to Computation  
Quantum Metrology  
Solid-State Quantum Light Sources  
Quantum Photonics

Nanoparticles



**Biotechnologies**



Singe-Molecule Studies and Imaging  
Biosensors and Diagnostic Devices  
Drug Delivery and Vaccine Development  
Biological and Biomimetic Structures

Extreme Ultraviolet Lithography



**Semiconductors and Microelectronics**



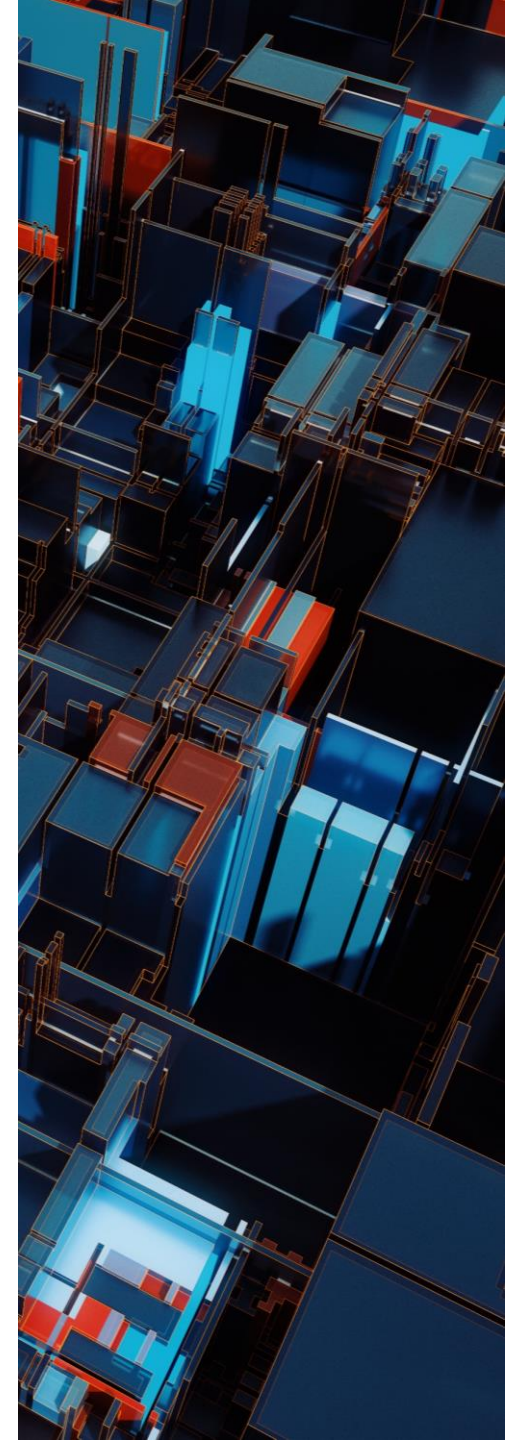
Automobiles  
Cell Phones  
Wearable Electronics  
Spacecraft

*...energy storage, and more critical and emerging technologies.*



# Study Statement of Task

- Explore **trends, opportunities, and emerging use cases** for nanoscale R&D and the impact of **infrastructure—including people, instruments, and facilities**
  - ❖ opportunities and barriers to the **nation's global leadership** in nanotechnology infrastructure
- Analyze the **composition of the science and engineering community** currently being served by the nation's **nanotechnology R&D infrastructure**.
- Identify **barriers to use** for communities who are not fully engaging with nanotechnology R&D infrastructure



# Study Committee

**Vicki L. Colvin**

Louisiana State University, *Chair*

**Catherine J. Murphy**

University of Illinois Urbana-Champaign, *Vice Chair*

**Omolola Eniola  
Adefeso**

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**Craig Arnold**

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**Angela M. Belcher**

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Stanford University

**Harold G. Craighead**

Cornell University, Emeritus

**Travis Earles**

Sonder.Works

**Y. Shirley Meng**

University of Chicago; Argonne National Laboratory

**Christine Payne**

Duke University

**Ricardo Ruiz**

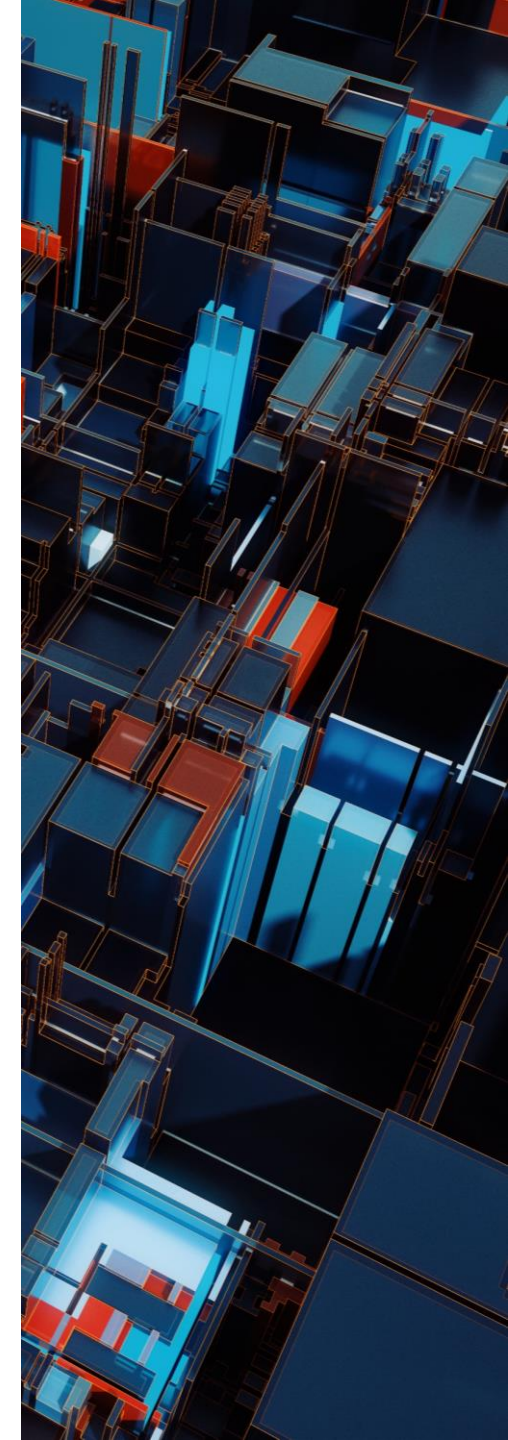
The Molecular Foundry,  
Lawrence Berkeley National Laboratory

**Michael G. Spencer**

Morgan State University

**Jesse B. Tice**

Northrop Grumman Corporation



# Study Process and Information Gathering

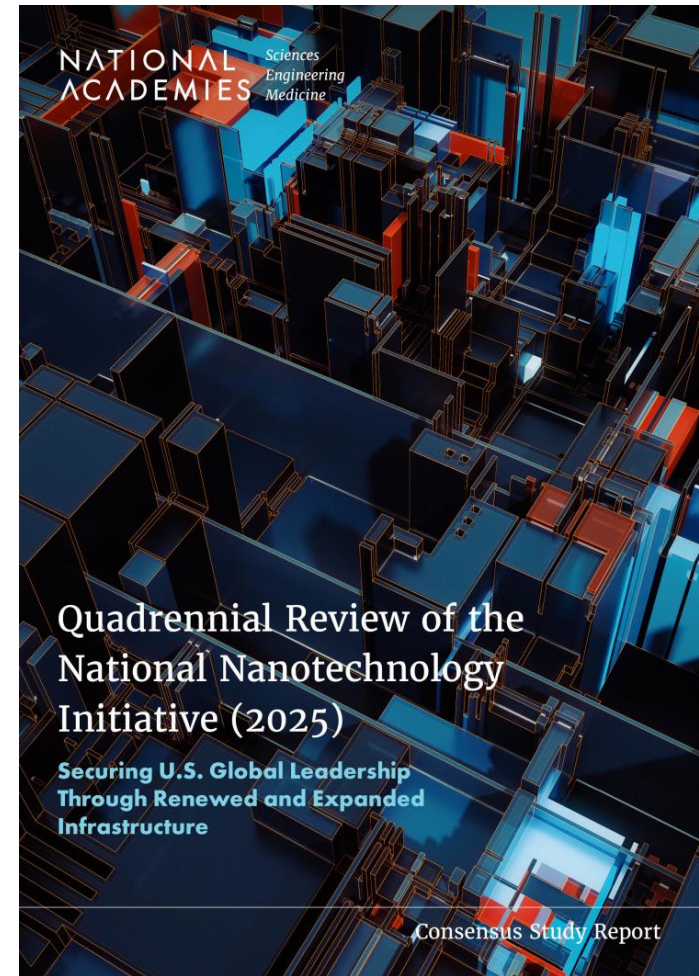
- **14 public information gathering sessions**, including 4 hybrid committee meetings
- Information gathering
  - **Data requests** sent to nanotechnology infrastructure facilities funded by the National Science Foundation and Department of Energy
  - Spoke with **51 experts** from across government, academia, and industry encompassing multiple perspectives
  - **Virtual town hall**
- **Briefings** to the National Nanotechnology Coordination Office, federal agencies, and Congressional Staffers





# About the Report – Key Takeaways

- **NNCO's role is critically important to the future of nanotechnology and U.S. technological competitiveness.** This coordination plays a vital role in ensuring researchers and industries are aware of U.S. infrastructure offerings.
- **Now is NOT the time to “sunset” this legislation** or curtail the blossoming commercial relevance of nanotechnology and limit the many benefits the nation will realize from its years of strategic investment.
- **Nanofabrication and characterization infrastructure are essential to support academic and industry research that can advance critical and emerging technology areas** like quantum information science and technology, microelectronics, biotechnology, advanced manufacturing, and artificial intelligence.
- Advancing nanotechnology infrastructure means **supporting the people, tools, and facilities** that make this groundbreaking R&D possible.



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# Priority Recommendations

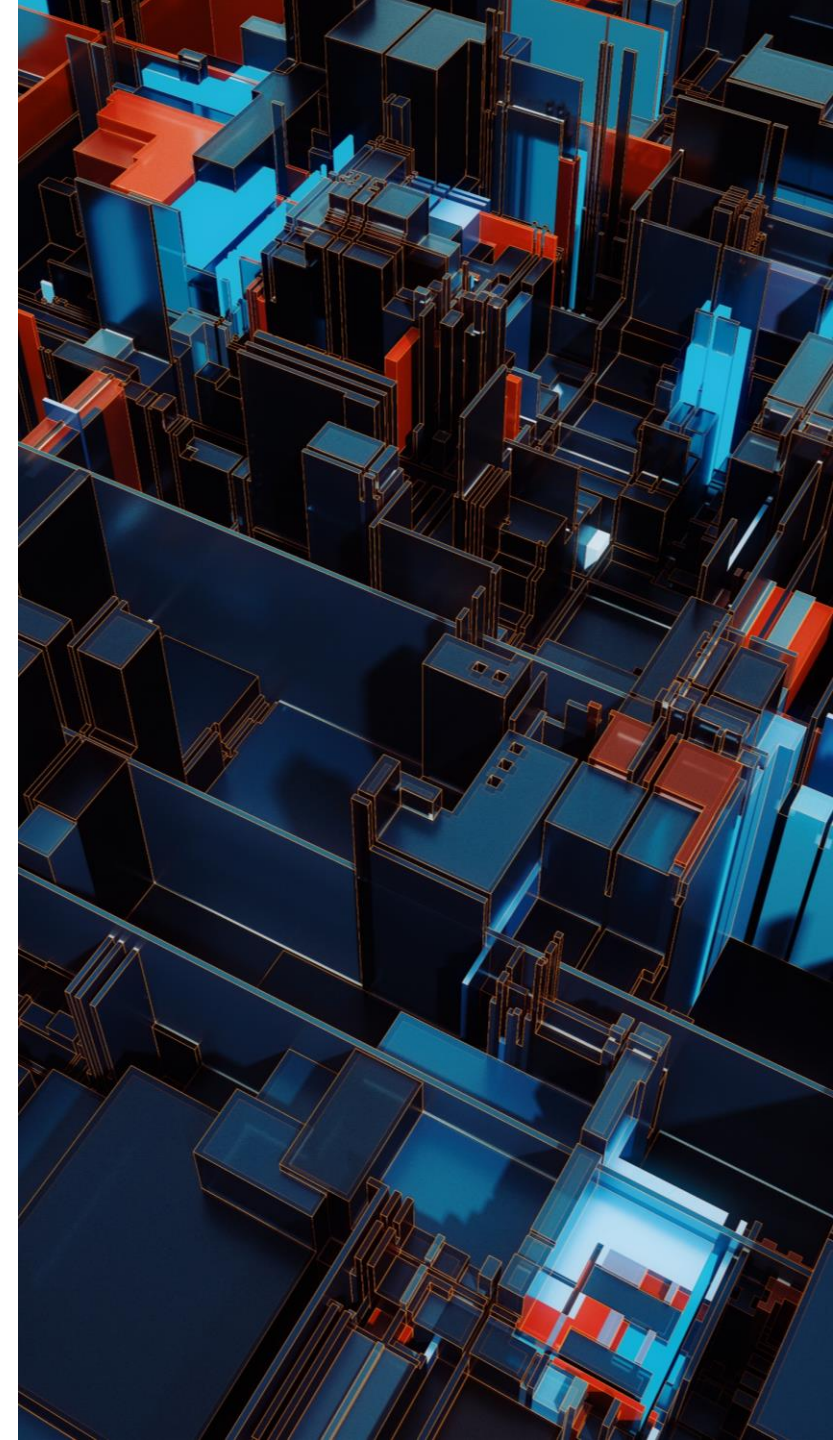


# Census of Infrastructure

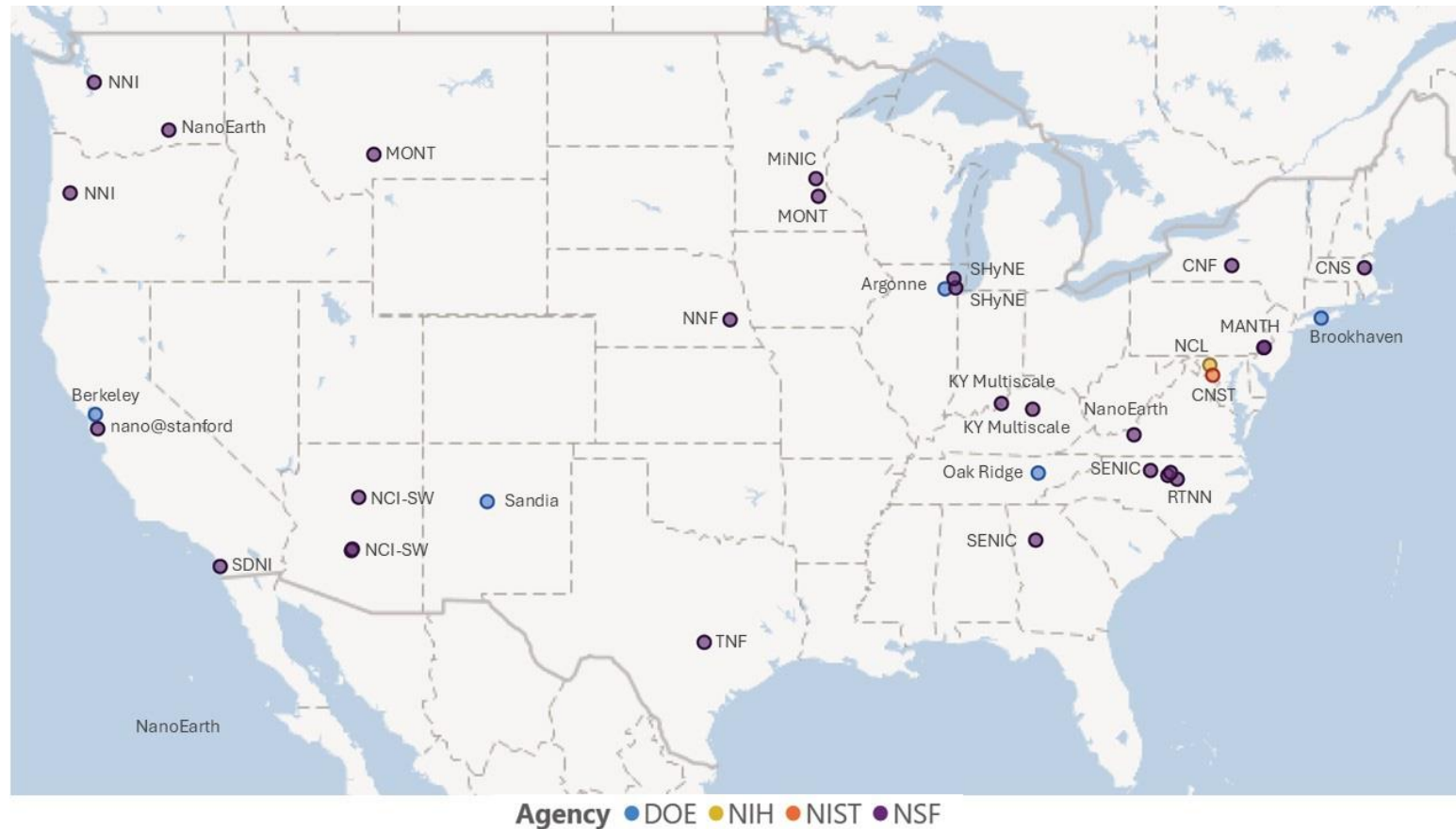
Finding 1.1: Nanotechnology is essential to numerous scientific disciplines and relevant to the missions of multiple federal agencies. Its interdisciplinary nature and broad impact means that there is no single home among the various science and engineering communities, nor is it predominantly overseen by any single government agency.

Finding 1.5: There is no single source of information on where particular infrastructure resources are located.

**Recommendation 1.1:** In the coming year, the National Nanotechnology Coordinating Office (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. This information, which should be maintained annually by NNCO, will enhance the visibility, availability, and impact of these assets.



# NNI Nanotechnology facilities across the United States



Nanotechnology facilities across the United States:

- National Science Foundation (NSF) National Nanotechnology Coordinated Infrastructure facility (*purple dots*)
- Department of Energy (DOE) Nanoscale Science Research Centers (*blue dots*)
- National Institute of Standards and Technology (NIST) facility (*orange dots*)
- National Institutes of Health (NIH) facility (*yellow dots*).

**TABLE 1-2** Examples of Major Research Universities with Their Own Nanotechnology Facilities That Are Not Part of the NNCI

Auburn University	Purdue University
Indiana University	Rice University
Iowa State University	University of Colorado
Louisiana State University	University of Florida
Massachusetts Institute of Technology	University of Illinois Urbana-Champaign
Michigan State University	University of Iowa
Ohio State University	University of Michigan
Pennsylvania State University	



# New Focus – National Nanotechnology Infrastructure

Finding 1.13: Every year, thousands of academic and industry researchers use the nanotechnology infrastructure.

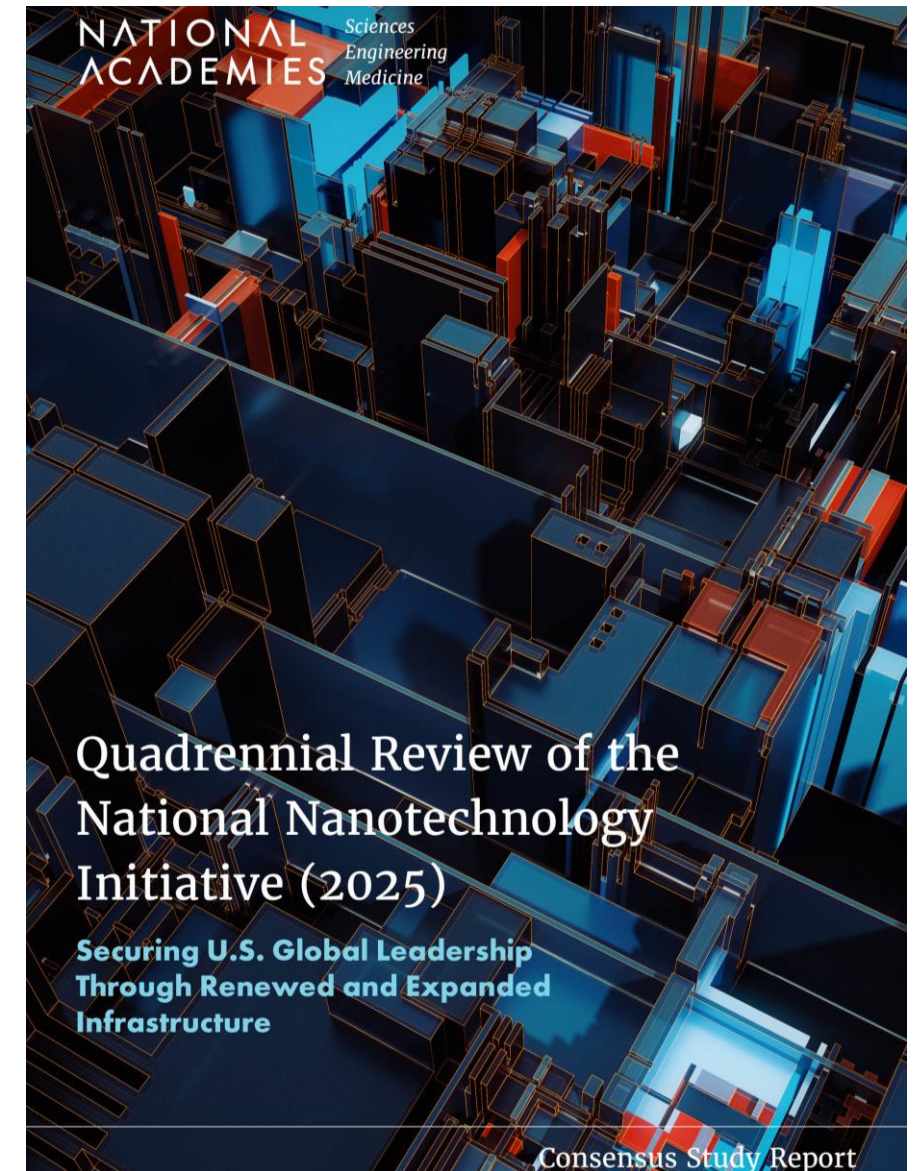
Finding 1.14: Nanofabrication and nanocharacterization infrastructure are essential to support academic and industry research that can advance **critical and emerging technology areas like quantum information science and technology, microelectronics, biotechnology, advanced manufacturing, and artificial intelligence.**

**Recommendation 1.2:** Within 2 years, Congress should **reauthorize the National Nanotechnology Initiative as the National Nanotechnology Infrastructure** and orient, with the appropriate funding, the National Nanotechnology Coordination Office and agency activity toward the renewal and expansion of infrastructure to serve existing and emerging nanotechnology research and development.

# State-of-the-Art Infrastructure

Finding 2.8: Given a levelized amortization of 10 years, approximately 10 percent of the total value of equipment would be needed annually to simply keep pace with the existing infrastructure, much less cover the typically higher cost of next-generation capabilities.

**Recommendation 2.4:** Within the next 2 years, the National Nanotechnology Coordination Office should **undertake a study to determine the level of resources needed to maintain state of-the-art nanotechnology infrastructure.** The study should include a timeframe, measures of success and efficiency, and accountability measures.





# Invest in new Capability to Maintain Commercial Edge

Finding 3.2: Nanotechnology integrates knowledge from a broad set of disciplines, and emerging areas of science and technology are leveraging and extending its infrastructures to advance their own disciplines.

Finding 3.4: The existing nanotechnology infrastructure has been available to researchers who otherwise would not consider themselves as working in nanotechnology, and this accessibility has been central to breakthroughs that have impact the lives of all Americans.

*Conclusion: Maintaining world-leading facility access is important for the U.S. economy and national security, as well as for ensuring continued leadership in science and engineering research.*

**Recommendation 3.3:** Federal agencies that support nanotechnology infrastructure should within the next year, and periodically thereafter, **prioritize investment in new capabilities that advance fabrication, materials synthesis, characterization, and data analysis to support emerging technologies** to help the United States maintain its commercial edge.





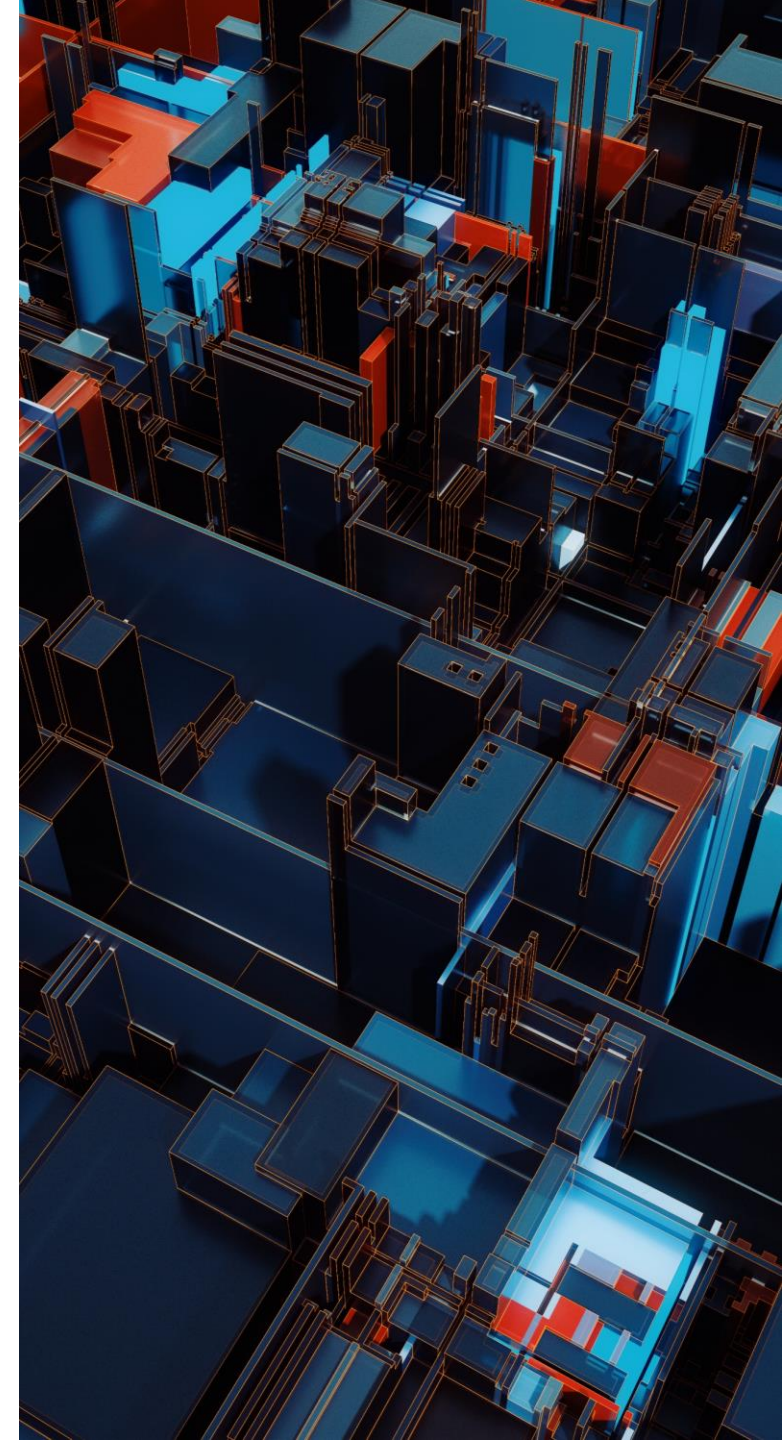
# Metrics that Capture User Bases

Finding 4.1: Infrastructure facilities are critical for training the future workforce for nanotechnology and other critical and emerging technologies

Finding 4.2: Outreach activities at NSF and DOE are outstanding in developing a nano-literate workforce; support a wide array of activities including K–12 programs, community college partnerships, R2 universities, and liberal arts programs

Finding 4.3: Programs are greatly limited in their scale by a lack of funding, which is generally a small proportion of the support for infrastructure facility operation; staff can be overburdened because these activities add to their research and facility training responsibilities, and the overall numbers of engaged participants is far lower than the projected workforce needs

**Recommendation 4.1:** All 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.**



# Funding for Travel

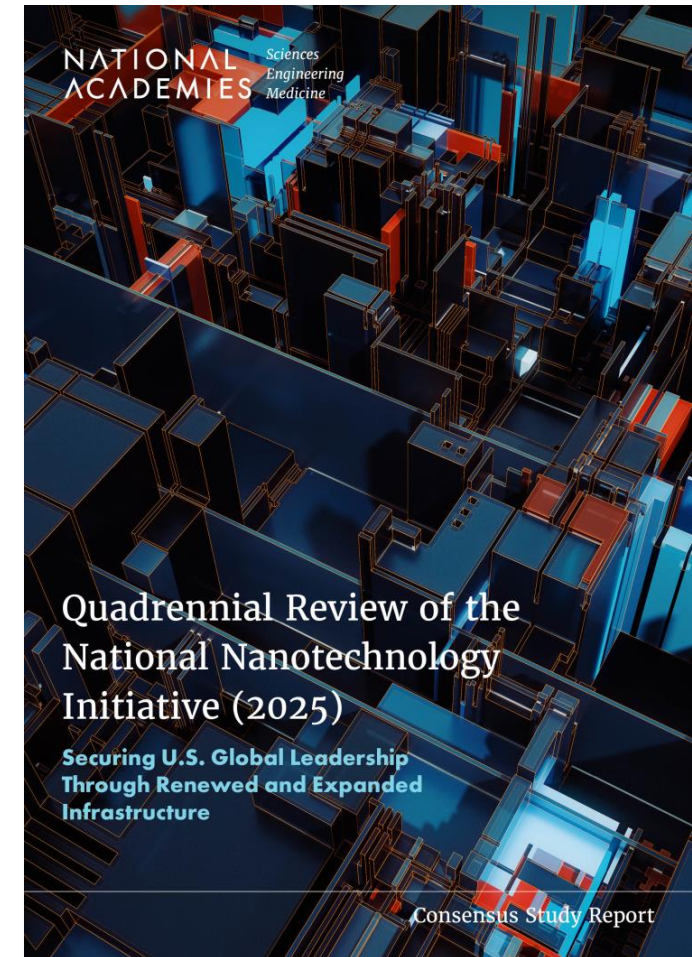
Finding 4.9: The cost of travel and housing are a major impediment to use of NNI facilities.

**Recommendation 4.5:** All agencies that fund nanotechnology infrastructure should **increase program funding or provide a competitive travel grant program** to include dedicated travel support for users and, where feasible, summer access for academics, researchers, and students who are not from R1 institutions.



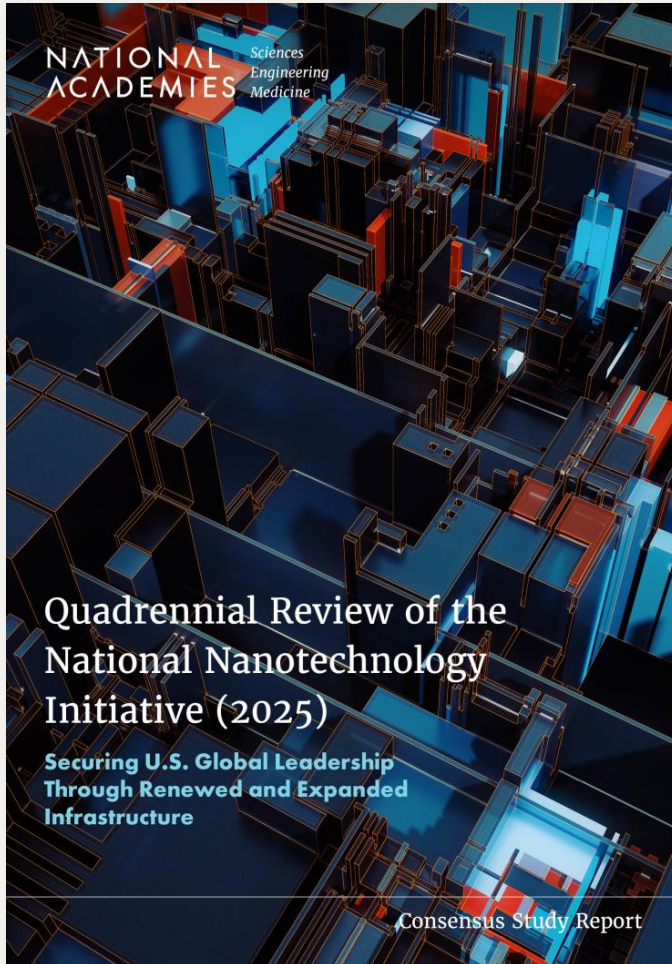
# Recap: Key Takeaways

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# Report Snapshot

- Summary
- 1: Introduction: What is the Nation's Nanotechnology Infrastructure?
- 2: Opportunities and Barriers for Renewing and Coordinating the Nation's Global Leadership in Nanotechnology Infrastructure R&D
- 3: Trends, Opportunities, and Emerging Use Cases for Next-Generation R&D Nanotechnology Infrastructure
- 4: Barriers to Use for Communities Not Fully Engaging in Nanotechnology Infrastructure
- 5: Conclusion and List of All Report Recommendations

# Thank You

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