# Synopsis of The Future of the NNI: A Stakeholder Workshop

The National Nanotechnology Initiative (NNI) hosted The Future of the NNI: A Stakeholder Workshop on August 1–2, 2019, in Washington, DC. The event convened representatives from organizations across the nanotechnology ecosystem, including academia, small and large companies, Federal agencies, standards development organizations, professional societies, non-governmental organizations, user facilities, and industry organizations. Through plenary discussions and breakout sessions, attendees shared their visions for how nanotechnology can enable and inspire future breakthroughs, and identified potential areas where nanotechnology is poised to have—and in some cases is already having—a significant impact. Conversations further explored key needs to support a vibrant nanotechnology ecosystem into the future, as well as possible mechanisms to address the identified needs.

The workshop included a town hall session for the nanotechnology community to provide input to the National Academies of Sciences, Engineering, and Medicine committee that is conducting a quadrennial review of the NNI.[1] During this session, participants shared a variety of views about the global position of the United States in nanotechnology research, the impact of the NNI, and the need for the initiative to continue. The plenary workshop sessions, including the town hall discussion, were webcast live; the archive is available on the workshop website.[2]

Nanotechnology can be applied in a wide variety of technical fields and industrial sectors, from electronics to national security and medicine. This breadth presents both a challenge and an opportunity. The applications and impacts of research and development activities carried out under the NNI can be diffuse and difficult to identify. A representative from a Fortune 500 company noted the impact of collaborating with academic researchers funded by NNI agencies and commented that, although not funded directly, advancements under the NNI benefited the company's work. While nanotechnology is applied as a tool across many application areas, the nanotechnology component is often not communicated because it is an enabler and not the end goal. Yet, nanotechnology has been a critical driver in key areas such as the semiconductor industry. Further, fundamental research into nanomaterials and nanoscale phenomena has resulted in new scientific sub-disciplines.

Given the broad applicability of nanotechnology, an important consideration for future activities is the relative emphasis placed on broad, fundamental research relative to targeted technical topics, application areas, or societal needs. Several attendees argued that a clear and compelling vision for the future could help frame program planning and guide progress. Many topics were mentioned as potential opportunity areas to prioritize, including batteries, sensors, electronics, precision agriculture, medicine, nanomanufacturing, water treatment, biosurveillance, environmental remediation, and devices to support quantum information science. The community could also explore ways to better identify breakthrough applications.

It was noted that it can take several decades or more after the emergence of a new technical field before products are commercialized and significant market impacts are seen, particularly in the biomedical field. As an example of how long research and development can take, one speaker said that it took eighteen months to get approval to do a study in a neonatal intensive care unit. It was suggested that a long-term perspective and sustained investments are required move technologies past the initial demonstration phase and into the market where they can impact people's lives.

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[1] https://www8.nationalacademies.org/pa/projectview.aspx?key=51396
[2] https://www.nano.gov/2019stakeholderworkshop

A recurring comment was that continued U.S. excellence in nanotechnology research and development depends on strong education and workforce development. One speaker underscored this point with the observation that “systems make it possible, but people make it happen.” The NNI has motivated universities and colleges to develop new courses and degree programs focused on nanotechnology and has fostered the establishment of networks for K-12 teachers and undergraduate students. The NNI also has played an important role in breaking down the silos between traditional academic disciplines and in fostering an interdisciplinary culture. Several participants observed that the NNI promoted cross-disciplinary approaches from the outset. For example, one scientist referenced a publication that had 45 authors from eight disciplines. Students trained in this interdisciplinary culture gain skills in collaboration and develop the confidence to explore new areas of science.

Nanotechnology research has been driven by significant advances in fabrication and characterization tools. One speaker suggested that improvements in tool capabilities under the NNI have “exponentially expanded the dimensions of understanding of matter,” providing the foundation for future breakthroughs. Further advances in the toolset will be driven by increased complexity in nanomaterials and systems and by application-specific requirements for areas such as manufacturing, quantum information science, and the nano-bio interface. Many attendees also commented on the need for continued development of informatics tools (e.g., databases and models).

A signature element of the NNI has been the development of a national network of user facilities, including 16 centers in the National Science Foundation-funded National Nanotechnology Coordinated Infrastructure and 5 Nanoscale Science Research Centers at Department of Energy National Laboratories. The NNI framework has facilitated cross-agency coordination and helped minimize redundancies across the network. These user facilities serve as a backbone for nanotechnology research in the United States by providing access to cutting-edge and expensive tools that individual universities or companies would otherwise not be able to purchase, and the technical expertise to fully utilize these tools. Several speakers said that their start-up companies relied extensively on nearby user facilities, highlighting the importance of local access to resources. A recurring challenge is the need to refresh user facilities so that the equipment remains at the cutting edge and able to support research in emerging areas.

Research funded and inspired through the NNI has identified many different applications that incorporate nanomaterials. Throughout the workshop, participants commented that economically producing large quantities of nanomaterials continues to be a challenge. Several breakout sessions noted a need to strengthen connections between fundamental manufacturing science and scale-up, including intermediate scale-up. Continued advances in real-time, *in situ* process monitoring and control are needed, as are additional standards for characterizing materials across length scales (i.e., nanoscale to macroscale). With respect to quality, batch-to-batch reproducibility remains an issue.

The challenges of commercializing nanotechnology-enabled innovations extend beyond the science. It is important for companies to develop intellectual property strategies, plan for regulatory compliance, and determine how their product offerings will interface with legacy systems and connect with the marketplace. Speakers mentioned several possible mechanisms to support small businesses and entrepreneurs as they navigate these challenges, including mentorship activities and programs that support market research and customer discovery. Public-private partnerships in topics such as nanoelectronics have been effective in advancing the science as well as in building communities across the supply chain and development cycle. The development of consortia in focused areas could be an effective way to identify and address technical bottlenecks that, once solved, could speed large-scale commercial adoption of nanomaterials and nanotechnology-enabled systems.