PROGRESS AND PLANS OF NATIONAL NANOTECHNOLOGY INITIATIVE (NNI) AGENCIES

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Department of Energy (DOE)[1]

Summary

The Department of Energy supports a broad portfolio of pioneering research and development in nanoscale science and engineering to promote scientific and technological innovation and to advance the agency's mission in ensuring the energy, economic, and national security of the United States. The majority of DOE NNI funding is managed by DOE's Office of Science, with additional support from the Office of Energy Efficiency and Renewable Energy, the Office of Fossil Energy, and the Office of Nuclear Energy. DOE supports nanoscale science and engineering research activities in academia, DOE national laboratories, and industry. For example, in support of its overall early-stage nuclear energy research mission and objectives, the Office of Nuclear Energy invests in nanotechnology-related research and experiments, executed primarily via competitive Nuclear Science User Facilities Consolidated Innovative Nuclear Research facility access awards and Rapid Turnaround Experiment (RTE) awards to researchers at U.S. universities and national laboratories. In addition, the Office of Science operates five Nanoscale Science Research Centers (NSRCs),[2] user facilities that provide open access to leading-edge synthesis, characterization, and computational tools and scientific expertise for interdisciplinary research at the nanoscale. Nanotechnology plays a vitally important role in addressing the Nation's energy, environmental, and national security challenges. DOE maintains a strong commitment to the NNI, which has served as an effective and valuable way to spotlight needs and target resources in this critical area of science and technology.

Plans and Priorities by Program Component Area (PCA)

PCA 1. Nanotechnology Signature Initiatives and Grand Challenges

1d. Sensors Nanotechnology Signature Initiative

The DOE Office of Fossil Energy is supporting basic and applied R&D on improved sensors and controls technologies for fossil-based electric power generation, including the use of nanostructured materials and novel architectures (e.g., nanowires and nanotubes), advanced manufacturing and fabrication techniques, integrated device design, packaging, high-temperature electronics, and signal processing. Real-time, multipoint, distributed sensing at the nanoscale will enable energy process optimization and component health prediction, thereby enhancing the flexibility, reliability, and efficiency of both existing and new fossil power plants.

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[2] See https://nsrcportal.sandia.gov/ for more information on the NSRCs, including names, locations, and technical specialties.

PCA 2. Foundational Research

The DOE Office of Basic Energy Sciences (BES) supports fundamental nanoscience research in the fields of materials science, chemical science, geoscience, and bioscience, with the goal of understanding, predicting, and ultimately controlling matter and energy at the level of electrons, atoms, and molecules. This work is carried out primarily at universities and DOE national laboratories through single-PI and small group projects as well as larger centers such as Energy Frontier Research Centers and Energy Innovation Hubs. This broad and diverse research provides the foundation for future new energy technologies and supports the DOE mission in energy, environment, and national security.

PCA 3. Nanotechnology-Enabled Applications, Devices, and Systems

The Office of Nuclear Energy supports projects focused on research and development, typically spanning a range of research, experiments, tests, and analyses that investigate:

- Behavior and properties of nuclear-energy-related materials that have been nanostructured or nano-modified, under various types of irradiation and conditions.
- Lower-length-scale changes in materials used in nuclear applications, which helps inform other nanostructure research (e.g., understanding radiation-induced changes to the nanometer-sized pores in fine-grained nuclear graphite, and modeling nanocluster evolution in irradiated ferritic oxide-dispersion-strengthened [ODS] and ferritic/martensitic alloys).

Also, a number of awarded projects include application of nanotechnology-enabled testing techniques, such as nanoindentation, which is particularly important to nanoscale-grained nuclear fuels.

PCA 4. Research Infrastructure and Instrumentation

BES operates five NSRCs, which are national user facilities for interdisciplinary R&D at the nanoscale that serve as the basis for a national program that encompasses new science, new tools, and new computing capabilities. The NSRC laboratories contain cleanrooms, nanofabrication resources, one-of-a-kind signature instruments, state-of-the-art electron microscopy, and other instruments not generally available except at major user facilities. Operating funds enable scientific staff that performs cutting-edge research and provides technical support through the user programs at these facilities, which are made available to academic, government, and industry researchers with access determined through external peer review of user proposals. The NSRCs provide training for graduate students and postdoctoral researchers in interdisciplinary nanoscale science, engineering, and technology research.

Key Technical Accomplishments by NNI Goal

Goal 1. Advance a World-Class Nanotechnology Research and Development Program

The majority of DOE NNI investment is from the Office of Basic Energy Sciences, with numerous projects across broad fields of research. The following are a few representative examples of key fiscal year (FY) 2018 accomplishments:

- *Truly secure communications. No eavesdropping.* That’s the promise of quantum communication. A critical component to making devices that harness the quantum world is a source that emits a regular stream of single photons. Scientists at the Center for Integrated Nanotechnologies and their colleagues chemically modified tiny tubes of carbon atoms. These tubes are the first materials to emit single photons at room temperature and telecom wavelengths. No other material system has been able to meet these two critical operational conditions simultaneously. Next the scientists identified how modified carbon nanotubes emit photon pairs. The experiments and theory show that the photon pairs are the result of the capture and recombination of two excitons (electron–hole pairs). The evidence suggests that this is an efficient process for generating photon pairs.[3]

- *Can you catch viruses with designer flypaper?* Researchers at the Molecular Foundry have developed a process for creating ultrathin, self-assembling sheets of synthetic materials that selectively bind with viruses, bacteria, and other pathogens. This is the first time that nanostructures have been engineered with such sophistication that they approach the structural precision and complexity found in nature.[4]
- Nanotextured glass surfaces can reduce light reflections to less than 0.2 percent across all visible and infrared light wavelengths. This reduction renders the glass essentially invisible—even at large viewing angles. These ultra-transparent windows could change cell phones, solar cells, and lasers. The material could enhance the experience of using consumer devices such as smart phones and televisions. Silicon solar cells encapsulated with "invisible glass" outperform conventional devices.[5]
- Although thin layers of graphene and other two-dimensional materials can be made on the small scale required for research, to be useful these materials must be manufactured on a much larger scale. Researchers produced large, single-crystal-like graphene films more than a foot long using a new method they developed. This method, which produces a single layer of graphene, relies on harnessing a "survival of the fittest" competition among graphene crystals.[6]
- *It set a Guinness world record. The highest resolution microscope in the world*. It clearly shows features as small as 0.39 ångströms. For comparison, most atoms are about 2 to 4 ångströms in diameter. Previously, electron microscopes were limited by the electron lenses in the microscope. Now, a team based at Cornell University has combined a scanning transmission electron microscope image reconstruction method with a new type of pixelated electron detector to obtain the highest-resolution images ever seen.[7]
- The physical and chemical properties of some materials change when they are confined to fit into the miniscule volume of a nanoparticle. Researchers have discovered that the internal structure of all-inorganic perovskite ($CsPbI_3$) nanoparticles is different than bulk formulations of the same material. In fact, the phase that has highly desirable optical absorption properties becomes more stable at the nanoscale than the phase typically found in larger crystals. The team built on this discovery, developing a "glue" that locks the nanocrystals together into conductive arrays. The arrays retain their excellent properties.[8]

The Office of Nuclear Energy reports the following key FY 2018 accomplishments:

- Awarded a three-year project to develop irradiation-resistant nanostructured thermoelectric materials and devices for in-pile power harvesting and sensing.
- Awarded a three-year project to obtain an understanding of swelling-related embrittlement of irradiated AISI 316 stainless steel on the nanometer length scale.

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[3] https://science.osti.gov/bes/highlights/2018/bes-2018-02-j/, https://science.osti.gov/bes/highlights/2018/bes-2018-08-c/

[4] https://science.osti.gov/bes/highlights/2018/bes-2018-07-b/

[5] https://science.osti.gov/bes/highlights/2018/bes-2018-06-a/

[6] https://science.osti.gov/bes/highlights/2018/bes-2018-08-f/

[7] https://science.osti.gov/bes/highlights/2018/bes-2018-09-b/

[8] https://science.osti.gov/bes/highlights/2018/bes-2018-02-m/

- Awarded a five-year project to understand and develop nanodispersion-strengthened metallic composites with enhanced neutron irradiation tolerance.
- Initiated a two-year project to understand the consequences of irradiation damage on capacitive discharge resistance welding of 14YWT and ferritic ODS alloys for cladding applications.
- Completed the first year of a three-year project to elucidate radiation effects on optical fiber sensor fused smart alloy parts with graded alloy composition manufactured by additive manufacturing processes.
- Completed the second year of a five-year innovative research project aimed at confirming and understanding enhanced irradiation tolerance of nuclear-application steels via nanostructuring by innovative manufacture techniques.
- Completed the second year of a three-year research project on developing a nanostructured bulk thermoelectric generator for efficient power harvesting for self-powered sensor networks.
- Awarded five new RTE projects, including one to industry, that address either nanostructured material behaviors or investigate nanostructural behavior in materials relevant to nuclear energy applications. Two of these studies have already been completed and three are ongoing.
- Completed ten RTE projects awarded in FY 2017 important to understanding nanostructured material behavior and nanostructural changes in materials important to innovative reactor applications.

Goal 2. Foster the Transfer of New Technologies into Products for Commercial and Public Benefit

The Aramco Research Center-Boston is working with scientists at the Center for Integrated Nanotechnologies at Sandia National Laboratories to investigate the nanoscale mechanisms that cause corrosion and its subsequent progression in steel.[9]

Goal 3. Develop and Sustain Educational Resources, a Skilled Workforce, and a Dynamic Infrastructure and Toolset to Advance Nanotechnology

As part of a $218 million DOE investment in the emerging field of quantum information science (QIS), the Office of Basic Energy Sciences announced seven awards totaling $30 million over three years to develop QIS infrastructure and support QIS research at the five Nanoscale Science Research Centers.[10]

[9] https://www.offshore-mag.com/articles/2018/06/aramco-assessing-corrosion-factors.html

[10] https://www.energy.gov/articles/department-energy-announces-218-million-quantum-information-science, https://science.osti.gov/~/media/bes/pdf/Funding/BES_QIS_NSRC_Awards_FY-2018.pdf