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 energy, environment, and national security. Nanotechnology plays a vitally important role in addressing the Nation's challenges, and DOE maintains a strong commitment to the NNI. DOE supports nanoscale science and engineering research activities in academia, DOE national laboratories, and industry, including small businesses. The majority of DOE NNI funding is managed by the Office of Science (SC), with additional support from the Office of Energy Efficiency and Renewable Energy (EERE), the Office of Nuclear Energy (NE), and the Office of Fossil Energy (FE). In addition to a diverse portfolio of fundamental nanoscience research in materials and chemical sciences, geoscience, and bioscience, SC operates five Nanoscale Science Research Centers (NSRCs), user facilities that provide open access to leading-edge synthesis, fabrication, characterization, and computational tools and scientific expertise for interdisciplinary research at the nanoscale. EERE's nine program offices invest in a wide range of nanotechnology-related research and development in support of its energy efficiency, renewable energy, and sustainable transportation missions, including nanocrystalline metals, nanocomposite materials, and atomically precise manufacturing. NE supports research and development projects across a wide field of science and engineering associated with nuclear energy technology, including behavior and properties of nuclear-energy-related materials that have been nanostructured or nano-modified. FE supports nanoscale materials, modeling, and manufacturing projects in areas such as advanced sensors and separation membranes.

Plans and Priorities by Program Component Area (PCA)

PCA 1. Nanotechnology Signature Initiatives and Grand Challenges

1a. Nanomanufacturing Signature Initiative

In honor of NanoDay on 10-9, DOE's Advanced Manufacturing Office (AMO) within EERE highlighted AMO's new and updated resources on "nanomanufacturing" research and development (R&D) projects. A factsheet with details for each project is posted on the AMO website.[2] Three of the projects (UT Dallas, Zyvex, and UCLA) support nanoelectronics-related research where atomically precise manufacturing (APM) can enable next-generation technologies as today's electronics industry approaches the limits of Moore's law. This suite of projects involves use of scanning probe microscopes (including scanning tunneling microscopes—STMs—

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[2] https://www.energy.gov/eere/amo/nanotechnology-day

and atomic force microscopes—AFMs) to manipulate individual atoms to create materials with novel electronic and other properties. The most basic of these is at UCLA, where researchers are building a molecular tool that first will be used to demonstrate atomically precise sculpting of a scanning probe microscope (SPM) tip. Next is a project led by UT-Dallas that is optimizing the speed, accuracy, and throughput of SPM tip movement, leading towards eventual fabrication of commercial quantities of atomically precise devices. UT-Dallas researchers have already developed several innovations that they have applied for patents on. Their latest innovation is a new control mode (enabling depassivation of single H dimers and allowing atomic resolution comparable to the best AFM) that already is included in the ZYVECTOR technology sold by their partner Zyvex. Finally, Zyvex has its own APM project that aims to achieve positional control of the dopant atoms to a much higher precision (±0.3 nm) than previously possible, building on recent advances in STMs. Zyvex's automated Si surface preparation process will work with upgraded STM arrays and allow new dopant atoms such as boron and aluminum that can enable fabrication of atomically precise devices with bipolar logic. In the fall of 2019, Zyvex partner NIST used these techniques to fabricate the first example of a 3 x 3 array that not only is a key step in developing APM—but also will enable better understanding of phenomena such as high-Tc superconductivity.

PCA 2. Foundational Research

The 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 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 enabled by nanoscale technologies will aid in energy process optimization and component health prediction, thereby enhancing the flexibility, reliability, and efficiency of both existing and new fossil power plants.

The Office of Fossil Energy is supporting basic and applied R&D on manufacturing coal-based carbon materials for separation membranes that will remove hydrocarbons and other unwanted species from contaminated water and industrial waste streams. Conventional polymer membranes are not compatible with harsh solvents, and conventional ceramic membranes cannot achieve the small pore sizes required for some separations. Nanoscale carbon materials have the potential to address both shortcomings, allowing for highly selective separations even in the presence of harsh solvents or elevated temperatures. This could obviate the need for thermal separation and purification (e.g., distillation), which is a huge consumer of energy due to water's high heat of vaporization.

PCA 4. Research Infrastructure and Instrumentation

The Office of Basic Energy Sciences operates five Nanoscale Science Research Centers, 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 perform cutting-edge research and provide 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

The majority of DOE NNI investment is from the Office of Basic Energy Sciences, with numerous projects across broad fields of research. All BES science highlights are posted on the DOE website.[3] The following are a few representative examples of key fiscal year (FY) 2019 accomplishments (in no particular order); a number involve use of NSRC user facilities:

- Engineering Living Scaffolds for Building Materials.[4]
- Nanocrystals Help Magnesium Batteries Go On-the-Move.[5]
- Improved Fuel Cell Catalysts with Less Platinum.[6]
- Taking Diamond Qubits for a Spin.[7]
- Tiny, Sugar-Coated Sheets Selectively Target Pathogens.[8]
- Simultaneous Clean and Repair.[9]
- Squeezed Quantum Dots Produce More Stable Light.[10]
- Too Close for Comfort: Nanoparticles Need Some Space to Transfer Energy.[11]

The Office of Nuclear Energy reports the following key FY 2019 accomplishments:

- Completed the first year of a three-year project to develop irradiation-resistant nanostructured thermoelectric materials and devices for in-pile power harvesting and sensing.
- Completed the first year of a three-year project to obtain an understanding of swelling-related embrittlement of irradiated AISI316 stainless steel on the nanometer length scale.
- Completed the first year of a five-year project to understand and develop nanodispersion-strengthened metallic composites with enhanced neutron irradiation tolerance.

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[3] https://science.osti.gov/bes/Highlights
[4] https://www.energy.gov/science/bes/articles/engineering-living-scaffolds-building-materials
[5] https://www.energy.gov/science/bes/articles/nanocrystals-help-magnesium-batteries-go-move
[6] https://www.energy.gov/science/bes/articles/improved-fuel-cell-catalysts-less-platinum
[7] https://www.energy.gov/science/bes/articles/taking-diamond-qubits-spin
[8] https://www.energy.gov/science/bes/articles/tiny-sugar-coated-sheets-selectively-target-pathogens
[9] https://www.energy.gov/science/bes/articles/simultaneous-clean-and-repair
[10] https://www.energy.gov/science/bes/articles/squeezed-quantum-dots-produce-more-stable-light
[11] https://www.energy.gov/science/bes/articles/too-close-comfort-nanoparticles-need-some-space-transfer-energy

- Completed the first year of a two-year project to understand the consequences of irradiation damage on capacitive discharge resistance welding of 14YWT and ferritic oxide-dispersion-strengthened (ODS) alloys for cladding applications.
- Completed the second 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 third 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 third year of a three-year research project on a nanostructured bulk thermoelectric generator for efficient power harvesting for self-powered sensor networks.
- Awarded 17 new rapid turnaround experiment (RTE) projects via the NE Nuclear Science User Facilities (NSUF) program that address either nanostructured material behaviors or investigate nanostructural behavior in materials relevant to nuclear energy applications.
- Completed five NSUF RTE projects awarded in FY 2018 that are important to understanding nanostructured material behavior and nanostructural changes in materials that are important to innovative reactor applications.