PROGRESS AND PLANS OF NATIONAL NANOTECHNOLOGY INITIATIVE (NNI) AGENCIES

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Department of Energy (DOE)

Summary

The Department of Energy supports a broad range of pioneering research and development in nanoscale science and engineering to promote scientific and technological innovation and benefit the agency's mission of advancing the energy, economic, and national security of the United States. The majority of DOE NNI funding is managed by DOE's Office of Science (SC), with additional support from the Office of Energy Efficiency and Renewable Energy (EERE), the Office of Fossil Energy (FE), and the Office of Nuclear Energy (NE). DOE supports nanoscale science and engineering research activities in university, industry, and DOE national laboratories. In addition, the Office of Science supports Nanoscale Science Research Centers (NSRCs), user facilities that provide access to leading-edge synthesis, characterization, and computational tools and scientific expertise for interdisciplinary research at the nanoscale. Nanotechnology has a vitally important role to play 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.

Key Technical Accomplishments by NNI Goal[1]

DOE-SC: The majority of DOE NNI investment is from the Office of Basic Energy Sciences (BES), with numerous projects across broad fields of research. The following are a few representative examples of key fiscal year (FY) 2017 accomplishments:

- A twisted array of atomic magnets were driven to move in a curved path, a needed level of control for use in future memory devices. For the first time, scientists have experimentally validated a theoretical prediction that magnetic skyrmions will move intact in a direction perpendicular to the electric current. This phenomenon is called the skyrmion Hall effect, an analogy to electrons with similar behavior. The high stability and easy manipulation of skyrmions could revolutionize energy-efficient information technologies including memory and logic devices.[2] [Goals 1 & 3]
- Scientists determined the three-dimensional position of more than 23,000 atoms in a tiny iron-platinum nanoparticle with 22 picometer precision. They correlated the observed chemical order/disorder and defects in the atomic structure with magnetic properties at the single-atom level. Much of our modern science and technology rely on materials with defects and disorder.

[1] For a list of NNI goals and Program Component Areas, see: https://www.nano.gov/about-nni/what/vision-goals.

[2] https://science.energy.gov/bes/highlights/2017/bes-2017-06-n/

Understanding the disorder—and its effect on material properties—is critical to designing improved materials for energy production, storage, and use. This work makes major advances in characterizing materials. It also expands our understanding of how a material's structure and behavior are related in defected materials.[3] [Goals 1 & 3]

- In conventional systems for converting sunlight to chemical fuels, a single photon, no matter how energetic, leads to a single electron-hole pair and thus a single electron-hole pair's worth of chemical work. The one-to-one situation limits devices that use sunlight to create chemical fuels. Scientists have overcome this limit and demonstrated for the first time that two electron-hole pairs, and two electron-hole pairs' worth of chemical work, can be produced from a single photon. This research could make the conversion of sunlight into chemical fuels more efficient by harvesting more energy from highly energetic photons. Conventional systems discard this excess energy as heat. Higher efficiency, in turn, means lower cost because it allows the device to produce more fuel per unit area of the solar cell and of the land supporting the cell.[4] [Goal 1]
- Researchers designed an extremely efficient catalytic system to remove carbon monoxide from ambient air. While we currently rely on carbon monoxide detectors for safety, new research points the way to a new approach: direct elimination of the gas. Collaborative research teams recently succeeded in creating tiny, uniquely structured wires that remove the gas from an enclosed area with 100 percent efficiency at room temperature. This work could lead to a highly efficient and cost-effective method to remove carbon monoxide. More broadly, the scientists showed how to maximize the activity of the tiny wires made from platinum and iron using an encased structure. This result provides insight towards the development of advanced catalysts, which could impact an incredibly large number of applications, such as fuel cell reaction systems.[5] [Goals 1 & 3]
- A new foam called the Oleo Sponge has been invented that not only easily adsorbs oil from water but is also reusable and can pull dispersed oil from an entire water column, not just the surface. Many materials can grab oil, but there hasn't been a way, until now, to permanently bind them into a useful structure. The scientists developed a technique to create a thin layer of metal oxide "primer" within the interior surfaces of polyurethane foam. Scientists then bound oil-loving molecules to the primer. The resulting block of foam can be wrung out to be reused, and the oil itself recovered. At tests in New Jersey's Ohmsett—The National Oil Spill Response Research & Renewable Energy Test Facility giant seawater tank, the Oleo Sponge successfully collected diesel fuel and crude oil from both below and on the water surface. Even after hundreds of wring and reuse cycles, the scientists have yet to observe any breakdown of the foam. The technique itself is quite flexible and can be adapted to other types of cleanup by attaching different molecules to target specific substances.[6] [Goals 1, 2, & 3]

DOE-EERE: Examples of key FY 2017 accomplishments resulting from NNI investments by the Office of Energy Efficiency and Renewable Energy include the following:

- Development of a nanoscale coating that results in high-energy Li-ion battery cells with greatly improved cycle life. Pouch cells constructed with this active material coating lose only 10% capacity after 1,000 cycles at 4.4 volts. This cycle life is more than two times better than that achieved by cells without the coating.

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[3] https://science.energy.gov/bes/highlights/2017/bes-2017-04-d/

[4] https://science.energy.gov/bes/highlights/2017/bes-2017-08-g/

[5] https://science.energy.gov/bes/highlights/2016/bes-2016-11-i/

[6] https://science.energy.gov/bes/highlights/2017/bes-2017-05-f/

- A new world record for highest efficiency in solar hydrogen production via photoelectrochemical (PEC) water-splitting using a nanostructured inverted metamorphic multi-junction (IMM) semiconductor device. The new solar-to-hydrogen efficiency record is 16.2%, topping a reported 14% efficiency in 2015 and the researchers' own previous record of 12% set in 1998. The achievement was enabled through the use of state-of-the-art IMM architecture, which allowed for a highly precise nanostructuring of functional layers, including III-V-based semiconductors as well as ultra-thin optical window and electronic interface layers. PEC offers a promising route to inexpensive, sustainable hydrogen fuel by harvesting light directly from the sun.
- Verification that the electrical conductivity of copper can be increased by 30% using nanocarbon.

DOE-NE: During FY 2017 the Office of Nuclear Energy completed four Rapid Turnaround Experiment (RTE) projects and awarded ten new RTE projects that address either nanostructured material behaviors or investigate nanostructural behavior in materials relevant to nuclear energy applications. Of particular importance is the investigation into irradiation response of nanostructured alloys that could be applied in next-generation reactors. [Goal 2]

Plans and Priorities by Program Component Area (PCA)

DOE-SC: 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 broad and diverse research provides the foundation for future new energy technologies and supports the DOE mission in energy, environment, and national security. In addition, BES operates 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. In FY 2019 BES plans to continue support for the five NSRCs. [PCAs 2 & 4]

DOE-EERE: Within the Office of Energy Efficiency and Renewable Energy, nanotechnology R&D projects are supported by the Vehicle Technologies Office, the Fuel Cell Technologies Office, and the Advanced Manufacturing Office. These projects emphasize applied research and nanotechnology development for applications in energy-relevant technologies. For example, several projects focus on nanoscale materials and designs to enhance high-energy and high-power lithium-ion batteries. This work includes research on nanoscale coatings for lithium metal anodes, nanoscale material architectures for silicon-based anodes, nanoscale lithium titanate anodes for high-power start/stop batteries, and nanoscale coatings on high-energy cathode materials. Other projects emphasize the incorporation of nanomaterials into manufacturing processes. [PCAs 2 & 3]

DOE-FE: The Office of Fossil Energy is continually seeking to accelerate the pace of innovation for sensors and controls (S&C) technologies, with the goal of improving efficiency, availability, resilience, and reliability for fossil-based electric power generation. The S&C portfolio features basic and applied R&D activities for advanced sensing elements, including nanostructured materials and novel architectures (e.g., nanowires and nanotubes). Investigation also includes advanced manufacturing and fabrication techniques (e.g., additive manufacturing, embedded sensors, wet and dry synthesis techniques, and spray coatings), integrated device design, packaging, high-temperature electronics, and signal processing. The cultivation of real-time, multi-point, distributed sensing at the nanoscale will significantly improve the amount of meaningful information and improve our fundamental understanding of energy processes. The interdisciplinary field of nanotechnology, which deals with the smallest, most fundamental scales of matter, will undoubtedly have a large impact on S&C technologies, pushing us beyond the current state of the art and constituting a breakthrough for the power plant industry. [PCA 1]

DOE-NE: The Office of Nuclear Energy expects to maintain its ongoing investment in nanotechnology-related research at national laboratories and universities, primarily through Nuclear Science User Facilities Consolidated Innovative Nuclear Research facility access awards and Rapid Turnaround Experiment awards. The focus will remain in the areas of confirming the benefits of nanostructuring via innovative manufacturing techniques, and advancing the understanding of nanoscale structural changes in materials important to advanced reactor and fuel applications. [PCA 3]