Nanoscale Science Research Centers

Portfolio Description

The Nanoscale Science Research Centers (NSRCs) are DOE's premier user centers for interdisciplinary research at the nanoscale, serving as the basis for a national program that encompasses new science, new tools, and new computing capabilities. Each center has particular expertise and capabilities in selected theme areas, such as synthesis and characterization of nanomaterials; catalysis; theory, modeling and simulation; electronic materials; nanoscale photonics; soft and biological materials; imaging and spectroscopy; and nanoscale integration. The centers are housed in custom designed laboratory buildings near one or more other major BES facilities for x-ray, neutron, or electron scattering, which complement and leverage the capabilities of the NSRCs. These laboratories contain clean rooms, nanofabrication resources, one-of-a-kind signature instruments, and other instruments not generally available or co-located except at major user facilities. These facilities are routinely made available on a scientific merit basis to the broad research community. There are five NSRCs:

- Center for Functional Nanomaterials (CFN) at Brookhaven National Laboratory
- Center for Integrated Nanotechnologies (CINT) at Los Alamos National Laboratory and Sandia National Laboratories
- Center for Nanophase Materials Sciences (CNMS) at Oak Ridge National Laboratory
- Center for Nanoscale Materials (CNM) at Argonne National Laboratory
- The Molecular Foundry (TMF) at Lawrence Berkeley National Laboratory

Unique Aspects

Nanotechnology is the understanding and control of matter at dimensions of roughly 1 to 100 nanometers (one billionth of a meter), where unique phenomena enable new applications. At these size scales, small numbers of atoms, molecules, and supramolecular structures exhibit new phenomena which produce novel electronic, optical, chemical and structural macroscopic properties. To discover, understand and synthesize nanostructures, NSRCs make available sophisticated research tools for nanoscience and nanotechnology to the broad scientific community, and facilitate access to other collocated major facilities including synchrotron radiation light sources, neutron scattering centers, and electron beam microcharacterization facilities. The NSRCs are the DOE signature activity in nanoscale research and constitute the nation's largest scientific infrastructure investment under the National Nanotechnology Initiative (NNI).

NSRCs provide unique scientific and engineering capabilities not available in any of the parallel programs sponsored by other entities. For example, other federal agencies sponsor research in nanoscience at universities, but such programs are generally limited in scope and size, are focused on specific research issues or topical areas, and primarily involve researchers of the host institution and a limited number of partners. The NSRCs are larger-scale facilities with a broad range of capabilities and are accessible without usage fees for non-proprietary work, with instrument time and staff support allocated on the basis of peer-review of proposals. The purposes of the NSRCs are as follows:

- Advance the fundamental understanding and control of phenomena and materials at the nanoscale regime.
- Provide an environment to support research of a scope, complexity, and disciplinary breadth

not possible under traditional individual investigator or small group efforts.
- Provide the foundation for the development of nanotechnologies important to DOE.
- Provide state-of-the-art equipment to in-house laboratory, university, and industry researchers and leverage the capabilities of national user facilities for materials characterization employing electrons, photons, and neutrons.
- Provide a formal mechanism for both short- and long-term collaborations and partnerships among DOE laboratory, academic, and industrial researchers.
- Provide training for graduate students and postdoctoral associates in interdisciplinary nanoscale science, engineering, and technology research.

Relationship to Other Programs
- The fundamental science being carried out at the NSRCs is closely related to BES programmatic research on the nanometer scale at both universities and national laboratories.
- Researchers supported by BES, by other parts of the Office of Science, by other parts of DOE, and by other federal agencies participate in the overall NSRC user community. While not a requirement, a major benefit is the opportunity for users to collaborate with the NSRC scientists. In addition, the NSRCs are collocated with, and serve as access points to, existing major BES user facilities for x-ray, neutron, and electron scattering.
- BES coordinates nanoscience activities with other federal agencies through the National Science and Technology Council (NSTC) Nanoscale Science, Engineering, and Technology subcommittee, which leads the National Nanotechnology Initiative.

Significant Accomplishments
All five NSRC facilities entered full user operations between FY 2006 and FY 2008. In the operations phase of the NSRCs, user activity has increased substantially from four operational centers with nearly 800 unique users in FY 2007 to the present five operating centers serving 2,300 users in FY 2013. Since their inception the NSRCs have served over 11,200 users and are essentially at capacity. Many new and exciting discoveries have emerged in a wide range of nanoscience areas. Research highlights include:
- The electron beam directed assembly of polymers with features relevant to terabit per square inch magnetic storage media,
- Novel metamaterials for next generation terahertz flat optics,
- Unprecedented spatial resolution hard xray optics for nanotomography,
- Precision polymer deuteration processes for neutron beam probing of soft material folding behavior, and
- Formation of the first 2D supramolecular organic framework with honeycomb periodicity using a novel solution-based self-assembly approach.

Mission Relevance
A part of the mission of the Office of Science is to "deliver the premier tools of science to our Nation's research enterprise." The NSRCs join the suite of major DOE user facilities that fulfill this objective. A seminal DOE-BES workshop and subsequent report on *Basic Research Needs to Assure a Secure Energy Future* cited nanoscience as a critical cross-cutting theme, and this has been reiterated in numerous follow-up reports on Basic Research Needs for specific focused aspects of energy research, such as the hydrogen economy, solar energy utilization, and solid-state lighting. In addition, BES and the National Science and Technology Council (NSTC) co-

sponsored a major workshop and report on *Nanoscience Research for Energy Needs* that identified key research targets and foundational themes for energy-related nanoscience. As stated in the Executive Summary of that report, "At the root of the opportunities provided by nanoscience to enhance our energy security is the fact that all of the elementary steps of energy conversion (e.g., charge transfer, molecular rearrangement, chemical reactions, etc.) take place on the nanoscale."

Scientific Challenges

Strategic investments in scientific areas of opportunity are necessary to help our nation develop a balanced research and development infrastructure, advance critical research areas, and nurture the scientific and technical workforce of the 21st century. Nanotechnology R&D is a top federal priority with broad potential implications for the nation's competitiveness. DOE's participation in this effort includes the development and operation of the NSRCs, whose goals include: (1) to attain a fundamental scientific understanding of nanoscale phenomena, particularly collective phenomena; (2) to achieve the ability to design and synthesize materials at the atomic level to produce materials with desired properties and functions; (3) to take full advantage of other existing major user facilities, and (4) to develop experimental characterization techniques and theory/modeling/simulation tools necessary to drive the nanoscale revolution.

There are a large number of specific scientific challenges, many of which benefit from the collocation of disparate disciplines in order to fabricate, assemble, and otherwise manipulate nanosized components. One of the most challenging scientific problems is interfacing hard and soft matter, i.e., the world of electronic and structural materials with the world of biomaterials. These centers employ advanced experimental and theoretical tools to tailor and control the functionality (e.g., detection ability and sensitivity), compatibility, performance, and integration of materials at such interfaces.

Projected Program Evolution

The NSRCs are in full operation phase. NSRC scientists have established significant major capabilities and leadership in several areas of nanoscience and work effectively with the large user community and their collocated beam facilities. The NSRCs had their Triennial Reviews in FY2012. The number of user proposals has steadily increased and acceptance rates have begun to decrease showing that the Centers are near or at capacity for their funding level. Publication productivity in high-impact journals and the increasing user demand are signs that the NSRCs have been assimilated into the national scientific infrastructure. The NSRCs are expected to perform as world-leading institutions, excelling both in scientific impact and productivity and in working with users.