U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON ENERGY & ENVIRONMENT

HEARING CHARTER

Department of Energy User Facilities: Utilizing the Tools of Science to Drive Innovation through Fundamental Research

Thursday, June 21, 2012
9:30 a.m. - 11:30 a.m.
2318 Rayburn House Office Building

PURPOSE

On Thursday, June 21, 2012, at 9:30 a.m. in Room 2318 of the Rayburn House Office Building, the Subcommittee on Energy and the Environment of the Committee on Science, Space, and Technology will hold a hearing entitled *"Department of Energy User Facilities: Utilizing the Tools of Science to Drive Innovation through Fundamental Research."* The purpose of this hearing is to examine the role the Department of Energy's (DOE) national scientific user facilities play in enabling basic research that drives innovation and economic growth. Additionally, the hearing will examine challenges and opportunities associated with user facility planning and management.

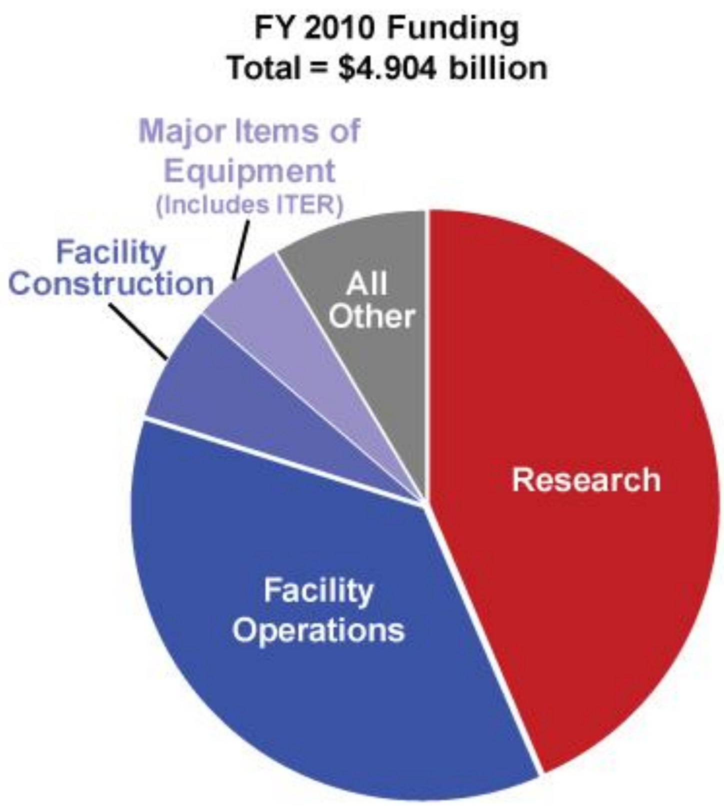
WITNESS LIST

- **Dr. Antonio Lanzirotti,** Chairman, National User Facility Organization
- **Dr. Persis Drell**, Director, SLAC National Accelerator Laboratory
- **Dr. Stephen Wasserman**, Senior Research Fellow, Translational Science & Technologies, Ely Lilly and Company
- **Ms. Suzy Tichenor**, Director, Industrial Partnerships Program, Computing and Computational Sciences, Oak Ridge National Laboratory
- **Dr. Ernest Hall,** Chief Scientist, Chemistry and Chemical Engineering/Materials Characterization, GE Global Research

Office of Science Overview

The mission of the Department of Energy's Office of Science (SC) is the delivery of scientific discoveries, capabilities, and major scientific tools to transform the understanding of nature and to advance the energy, economic, and national security of the United States.[1] To achieve this mission, SC supports basic research activities in the following areas: advanced scientific computing, basic energy sciences, biological and environmental research, fusion energy sciences, high energy physics, and nuclear physics. SC's operations take place in three main areas: selection and management of research (47 percent of SC's $4.9 billion FY 2013 budget request); operation of world-class, state-of-the-art scientific facilities (38 percent); and design and construction of new facilities (14 percent) (Figure 1).[2]

Figure 1. Office of Science funding distribution.



SC aims to carry out its mission through support in the following three areas:[3]

- Energy and Environmental Science, focused on advancing a clean energy agenda through fundamental research on energy production, storage, transmission, and use, and on advancing our understanding of the earth's climate through basic research in atmospheric and environmental sciences and climate change;

[1] http://science.energy.gov/about/
[2] *Ibid.*
[3] *Ibid*.

- The Frontiers of Science, focused on unraveling nature's mysteries—from the study of subatomic particles, atoms, and molecules that make up the materials of our everyday world to DNA, proteins, cells, and entire biological systems; and

- The 21st Century Tools of Science, national scientific user facilities providing the Nation's researchers with the most advanced tools of modern science including accelerators, colliders, supercomputers, light sources, neutron sources, and facilities for studying the nanoworld.

Office of Science User Facilities

This third category—national scientific user facilities—is a unique and defining characteristic of SC. The origins of these facilities trace back to the Manhattan Project, where the challenges associated with building the first nuclear weapons demanded large, multi-purpose facilities that later became the focus of the country's first national laboratories. DOE states that these facilities—the large machines for modern science—"offer capabilities unmatched anywhere in the world and enable U.S. researchers and industries to remain at the forefront of science, technology, and innovation. Approximately 26,500 researchers from universities, national laboratories, industry, and international partners are expected to use the Office of Science scientific user facilities in FY 2013."[4] According to the National User Facility Organization (NUFO), scientific user facilities (most but not all of which are supported by SC) were home to experiments that have resulted in 23 Nobel Prizes from 1939 until today.[5]

A January 6, 2012 Office of Science memorandum provides the following definition of a user facility: [6]

> "A user facility is a federally sponsored research facility available for external use to advance scientific or technical knowledge under the following conditions:
>
> - The facility is open to all interested potential users without regard to nationality or institutional affiliation.
> - Allocation of facility resources is determined by merit review of the proposed work.
> - User fees are not charged for non-proprietary work if the user intends to publish the research results in the open literature. Full cost recovery is required for proprietary work.
> - The facility provides resources sufficient for users to conduct work safely and efficiently.
> - The facility supports a formal user organization to represent the users and facilitate sharing of information, forming collaborations, and organizing research efforts among users.
> - The facility capability does not compete with an available private sector capability."

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[4] http://science.energy.gov/about/
[5] http://www.nufo.org/files/NUFO_Brochure.pdf
[6] http://science.energy.gov/~/media/_/pdf/user-facilities/Office_of_Science_User_Facility_Definition_Memo.pdf

Currently, the Office of Science supports 31 user facilities (Appendices I and II) across its six program directorates. They include supercomputers, particle accelerators, x-ray light sources, neutron scattering sources, and other large scale facilities that enable researchers to pursue new scientific discoveries.

Over half of these are located in the Basic Energy Sciences (BES) directorate and are focused on enabling cutting-edge physical and life sciences research with a broad range of potential applications. For example, BES supports five x-ray light sources used to examine the atomic and electronic structure of a wide array of materials and chemicals.[7] The research undertaken at these light sources by academia, government, and industry has resulted in numerous breakthroughs and innovations ultimately applied to advances in industry sectors such as aerospace, medicine, semiconductors, chemicals, and energy.

Budget, Planning, Management, and Operations

Most SC user facilities are expensive to construct and operate, typically costing several hundred million dollars or more. For example, two of the most recently completed facilities—the Spallation Neutron Source at Oak Ridge National Laboratory and the Linac Coherent Light Source at SLAC National Accelerator Facility—cost $1.6 billion and approximately $415 million to construct, respectively.[8]

The Office of Science is generally well regarded for its effectiveness in planning, developing, and constructing user facilities on time and on budget. This record is considered successful in part due to a rigorous planning and budget control process known as the Critical Decision, or CD, process. The CD process, formalized in DOE Order 413.3A—Program and Project Management for the Acquisition of Capital Assets—requires a series of high level reviews and decision-making as a facility project advances.[9]

According to DOE, each of the five Critical Decisions mark "an increase in commitment of resources by the Department and requires successful completion of the preceding phase or Critical Decision."[10] Collectively, the Critical Decisions affirm the following:

CD 0: There is a need that cannot be met through other than material means;
CD 1: The selected alternative and approach is the optimum solution;
CD 2: Definitive scope, schedule and cost baselines have been developed;
CD 3: The project is ready for implementation; and
CD 4: The project is ready for turnover or transition to operations.

Once facility construction has completed and transitioned into operations and research, Office of Science programs typically provide significant ongoing support to manage and operate facilities (Table 1). Support for merit-reviewed research undertaken by both intramural and extramural scientists is also provided by SC, as well as by other Federal agencies.

[7] http://science.energy.gov/~/media/bes/suf/pdf/BES_Facilities.pdf
[8] http://energy.gov/sites/prod/files/maprod/documents/LCLS.pdf
[9] http://science.energy.gov/~/media/pdf/opa/pdf/o4133a.pdf
[10] *Ibid.*

Table 1. Office of Science Program and Facility Operations Budgets.[11]

Program	**FY12 Total Budget** ($ millions)	**FY12 User Facility Operations*** ($ millions)
Advanced Scientific Computing Research (ASCR)	440.9	248.3
Basic Energy Sciences (BES)	1,688.1	730.6
Biological and Environmental Research (BER) *	609.6	201.7
High Energy Physics (HEP)	790.8	221.6
Nuclear Physics (HP)	547.4	289.3
Fusion Energy Sciences (FES)*	401.0	129.7

* Table figures do not include facilities research support, with the exception of BER and FES directorates, which do.

Innovation and Industrial Use

A 2010 report by DOE's Basic Energy Sciences Advisory Committee (BESAC), *Science for Energy Technology: Strengthening the Link Between Basic Research and Industry*, examined challenges and opportunities associated with realizing the technological and economic potential of scientific user facilities.[12] The report noted that these user facilities allow researchers to "peer deep inside objects and probe surfaces in ever increasing detail, enabling an understanding of complex materials and chemistry with resolution and sensitivity that is not achievable by any other means. Facilities of this type are well beyond the resources of individual research institutions or companies."[13]

The report also concluded that opportunities exist for user facilities to better engage and improve industrial usage without deviating from their fundamental mission to broadly advance science. Specifically, the report made the following recommendations with respect to user facilities:

- The user facilities are ideally suited to addressing a wide range of science questions with significant technological impact. BES and the user facilities could consider a number of options that would allow the facilities to better serve the industrial user community without deviating from their mission to advance scientific understanding of materials and chemical processes.
- To the extent possible, it would be desirable to have more uniform procedures for access and use across the various user facilities to expedite coordinated use of multiple facilities by industry and other research organizations.
- Evaluation of proposals could take into consideration technological impact in addition to scientific merit.

[11] Source Department of Energy Fiscal Year 2013 Budget Request.
[12] http://science.energy.gov/~/media/bes/pdf/reports/files/set_rpt.pdf
[13] *Ibid.*

- Peer review of proposals could include a greater number of industry reviewers.
- The facilities might consider setting aside a modest fraction of the facility time for "quick response" projects from industry and basic science users.
- User facility staff researchers could be incentivized and rewarded for assisting non-expert users from industry, and facilities could increase their outreach to industry by holding workshops to gain greater understanding of industrial needs and barriers to increased participation.
- These activities are within the technology transfer mission of the laboratories and could significantly enhance the development of clean energy technology.
- User facilities could be encouraged to develop and broaden industrial participation. Some possibilities include greater industrial participation on Scientific Advisory Committees, or possibly the development of a separate Industrial Advisory Board.
- These would help to develop better communications with the facility Director and staff regarding industrial needs for access, as well as new capabilities, instrumentation and beamlines.

Appendix I [14]

U.S. Department of Energy
Office of Science User Facilities, FY 2012

Facility	Host institution
Advanced Scientific Research Computing (ASCR)	
National Energy Research Scientific Computing Center (NERSC)	LBNL
Argonne Leadership Computing Facility (ALCF)	ANL
Oak Ridge Leadership Computing Facility (OLCF)	ORNL
Energy Sciences Network (ESnet)	LBNL
Basic Energy Sciences (BES)	
Light Sources	
Advanced Light Source (ALS)	LBNL
Advanced Photon Source (APS)	ANL
Linac Coherent Light Source (LCLS)	SLAC
National Synchrotron Light Source (NSLS)	BNL
Stanford Synchrotron Radiation Light Source (SSRL)	SLAC
Neutron Sources	
High Flux Isotope Reactor (HFIR)	ORNL
Spallation Neutron Source (SNS)	ORNL
Lujan at Los Alamos Neutron Science Center (LANSCE)	LANL
Nanoscale Science Research Centers	
Center for Functional Nanomaterials (CFN)	BNL
Center for Integrated Nanotechnologies (CINT)	Sandia/LANL
Center for Nanophase Materials Sciences (CNMS)	ORNL
Center for Nanoscale Materials (CNM)	ANL
The Molecular Foundry	LBNL
Electron Microscopy Centers	
National Center for Electron Microscopy (NCEM)	LBNL
Electron Microscopy Center for Materials Research	ANL
Shared Research Equipment Program (ShaRE)	ORNL
Biological and Environmental Research (BER)	
Environmental Molecular Sciences Laboratory (EMSL)	PNNL
Atmospheric Radiation Measurement Climate Research (ARM)	Global network
Joint Genome Institute (JGI)	LBNL
Fusion Energy Sciences (FES)	
DIII-D	General Atomics
National Spherical Torus Experiment (NSTX)	PPPL
Alcator C-Mod	MIT
High Energy Physics (HEP)	
Proton Accelerator Complex	FNAL
Facility for Advanced Accelerator Experimental Tests (FACET)	SLAC
Nuclear Physics (NP)	
Continuous Electron Beam Accelerator Facility (CEBAF)	TJNAF
Holifield Radioactive Ion Beam Facility (HRIBF)	ORNL
Relativistic Heavy Ion Collider (RHIC)	BNL
Argonne Tandem Linac Accelerator System (ATLAS)	ANL

Note: This list reflects facility status as of the beginning of the fiscal year and does not reflect changes in facility status enacted in appropriations law for FY 2012.

[14] http://science.energy.gov/~/media/_/pdf/user-facilities/Office_of_Science_User_Facility_Definition_Memo.pdf

Appendix II

Office of Science User Facility Descriptions (condensed from DOE materials)[15]

ASCR User Facilities

The Advanced Scientific Computing Research program supports the operation of the following national scientific user facilities:

- Energy Sciences Network (ESnet):
  The Energy Sciences Network, or ESnet, is a high-speed network serving thousands of Department of Energy researchers and collaborators worldwide. Managed and operated by the ESnet staff at Lawrence Berkeley National Laboratory, ESnet provides direct connections to more than 30 DOE sites at speeds up to 10 gigabits per second. Connectivity to the global Internet is maintained through "peering" arrangements with more than 100 other Internet service providers.
- Oak Ridge National Laboratory Leadership Computing Facility (OLCF):
  Home to Jaguar, a Cray XK6 capable of 3.3 thousand trillion calculations a second—or 3.3 petaflops—the OLCF combines world-class staff with cutting-edge facilities and support systems. The center serves elite scientists from all areas of the research community through programs such as the Department of Energy's Innovative and Novel Computational Impact on Theory and Experiment (INCITE) program, ensuring it will be a computing powerhouse for the foreseeable future. In 2012, nearly a billion processor hours on Jaguar were awarded to 35 INCITE projects from universities, private industry, and government research laboratories, representing a wide array of scientific inquiry, from combustion to climate to chemistry.
- Argonne Leadership Computing Facility (ALCF):
  The ALCF provides the computational science community with a world-class computing capability dedicated to breakthrough science and engineering. It began operation in 2006 to coincide with the award of the 2006 INCITE projects and the research being conducted at the ALCF spans a diverse range of scientific areas - from studying exploding stars to designing more efficient jet engines to exploring the molecular basis of Parkinson's disease. The resources at the ALCF include an IBM Blue Gene/P system nicknamed Intrepid, and a BG/P system named Surveyor. Intrepid possess a peak speed of 557 Teraflops and a Linpack speed of 450 Teraflops, making it one of the fastest supercomputers in the world.
- National Energy Research Scientific Computing (NERSC) Center:
  As a national resource to enable scientific advances to support the missions of the Department of Energy's Office of Science, the National Energy Research Scientific Computing Center (NERSC), operated by the Lawrence Berkeley National Laboratory, annually serves approximately 3,000 scientists throughout the United States. These researchers work at DOE laboratories, universities, industrial laboratories and other Federal agencies. Computational science conducted at NERSC covers the entire range of scientific disciplines, but is focused on research that supports DOE's missions and scientific goals.

[15] http://science.energy.gov/user-facilities

BES User Facilities

The Basic Energy Sciences program supports the operation of the following national scientific user facilities:

Synchrotron Radiation Light Sources

- National Synchrotron Light Source (NSLS):
  The NSLS at Brookhaven National Laboratory, commissioned in 1982, consists of two distinct electron storage rings. The x-ray storage ring is 170 meters in circumference and can accommodate 60 beamlines or experimental stations, and the vacuum-ultraviolet (VUV) storage ring can provide 25 additional beamlines around its circumference of 51 meters. Synchrotron light from the x-ray ring is used to determine the atomic structure of materials using diffraction, absorption, and imaging techniques. Experiments at the VUV ring help solve the atomic and electronic structure as well as the magnetic properties of a wide array of materials. These data are fundamentally important to virtually all of the physical and life sciences as well as providing immensely useful information for practical applications. NSLS will be replaced by a new light source, NSLS-II, which is currently under construction.
- Stanford Synchrotron Radiation Lightsource (SSRL):
  The SSRL at SLAC National Accelerator Laboratory was built in 1974 to take and use for synchrotron studies the intense x-ray beams from the SPEAR storage ring that was originally built for particle. The facility is used by researchers from industry, government laboratories, and universities. These include astronomers, biologists, chemical engineers, chemists, electrical engineers, environmental scientists, geologists, materials scientists, and physicists.
- Advanced Light Source (ALS):
  The ALS at Lawrence Berkeley National Laboratory, began operations in October 1993 as one of the world's brightest sources of high-quality, reliable vacuum-ultraviolet (VUV) light and long-wavelength (soft) x-rays for probing the electronic and magnetic structure of atoms, molecules, and solids, such as those for high-temperature superconductors. The high brightness and coherence of the ALS light are particularly suited for soft x-ray imaging of biological structures, environmental samples, polymers, magnetic nanostructures, and other inhomogeneous materials. Other uses of the ALS include holography, interferometry, and the study of molecules adsorbed on solid surfaces. The pulsed nature of the ALS light offers special opportunities for time resolved research, such as the dynamics of chemical reactions. Shorter wavelength x-rays are also used at structural biology experimental stations for x-ray crystallography and x-ray spectroscopy of proteins and other important biological macromolecules.
- Advanced Photon Source (APS):
  The APS at Argonne National Laboratory is one of only three third-generation, hard x-ray synchrotron radiation light sources in the world. The 1,104-meter circumference facility—large enough to house a baseball park in its center—includes 34 bending magnets and 34 insertion devices, which generate a capacity of 68 beamlines for experimental research. Instruments on these beamlines attract researchers to study the structure and properties of materials in a variety of disciplines, including condensed matter physics, materials sciences, chemistry, geosciences, structural biology, medical imaging, and environmental sciences. The high-quality, reliable x-ray beams at the APS have already brought about new discoveries in materials structure.
- Linac Coherent Light Source (LCLS):
  The LCLS at the SLAC National Accelerator Laboratory (SLAC) is the world's first hard x-ray free electron laser facility and became operational in June 2010. This is a milestone for x-ray user facilities that advances the state-of-the-art from storage-ring-based third generation synchrotron light sources to a fourth generation Linac-based light source. The LCLS provides laser-like

radiation in the x-ray region of the spectrum that is 10 billion times greater in peak power and peak brightness than any existing coherent x-ray light source.

High-Flux Neutron Sources

- Spallation Neutron Source (SNS):
  The SNS at Oak Ridge National Laboratory is a next-generation short-pulse spallation neutron source for neutron scattering that is significantly more powerful (by about a factor of 10) than the best spallation neutron source now in existence. The SNS consists of a linac-ring accelerator system that delivers short (microsecond) proton pulses to a target/moderator system where neutrons are produced by a process called spallation. The neutrons so produced are then used for neutron scattering experiments. Specially designed scientific instruments use these pulsed neutron beams for a wide variety of investigations.
- High Flux Isotope Reactor (HFIR):
  The HFIR at Oak Ridge National Laboratory is a light-water cooled and moderated reactor that began full-power operations in 1966 at the design power level of 100 megawatts. Currently, HFIR operates at 85 megawatts to provide state-of-the-art facilities for neutron scattering, materials irradiation, and neutron activation analysis and is the world's leading source of elements heavier than plutonium for research, medicine, and industrial applications. The neutron-scattering experiments at the reveal the structure and dynamics of a very wide range of materials. The neutron-scattering instruments installed on the four horizontal beam tubes are used in fundamental studies of materials of interest to solid-state physicists, chemists, biologists, polymer scientists, metallurgists, and colloid scientists.
- Los Alamos Neutron Science Center (LANSCE):
  The Lujan Neutron Scattering Center (Lujan Center) at Los Alamos National Laboratory provides an intense pulsed source of neutrons to a variety of spectrometers for neutron scattering studies. The Lujan Center features instruments for measurement of high-pressure and high-temperature samples, strain measurement, liquid studies, and texture measurement. The facility has a long history and extensive experience in handling actinide samples. The Lujan Center is part of LANSCE, which is comprised of a high-power 800-MeV proton linear accelerator, a proton storage ring, production targets to the Lujan Center, the Weapons Neutron Research facility, Proton Radiography, and Ultra-Cold Neutron beam lines, in addition to an Isotope Production Facility, along with a variety of associated experiment areas and spectrometers for national security research and civilian research.

Electron Beam Microcharacterization Centers

- The Electron Microscopy Center (EMC) for Materials Research:
  The EMCMR at Argonne National Laboratory provides in-situ, high-voltage and intermediate voltage, high-spatial resolution electron microscope capabilities for direct observation of ion-solid interactions during irradiation of samples with high-energy ion beams. The EMC employs both a tandem accelerator and an ion implanter in conjunction with a transmission electron microscope for simultaneous ion irradiation and electron beam microcharacterization. It is the only instrumentation of its type in the western hemisphere. Research at EMC includes microscopy based studies on high-temperature superconducting materials, irradiation effects in metals and semiconductors, phase transformations, and processing related structure and chemistry of interfaces in thin films.
- National Center for Electron Microscopy (NCEM):
  The NCEM at Lawrence Berkeley National Laboratory provides instrumentation for high-resolution, electron-optical microcharacterization of atomic structure and composition of metals,

ceramics, semiconductors, superconductors, and magnetic materials. This facility contains one of the highest resolution electron microscopes in the U.S.

- Shared Research Equipment (SHaRE):
  The SHaRE User Facility at Oak Ridge National Laboratory makes available state-of-the-art electron beam microcharacterization facilities for collaboration with researchers from universities, industry and other government laboratories. Most SHaRE projects seek correlations at the microscopic or atomic scale between structure and properties in a wide range of metallic, ceramic, and other structural materials. A diversity of research projects has been conducted, such as the characterization of magnetic materials, catalysts, semiconductor device materials, high Tc superconductors, and surface-modified polymers. Analytical services (service microscopy) which can be purchased from commercial laboratories are not possible through SHaRE.

Nanoscale Science Research Centers

- Center for Nanophase Materials Sciences (CNMS):
  The CNMS at Oak Ridge National Laboratory is a research center and user facility that integrates nanoscale science research with neutron science, synthesis science, and theory/modeling/simulation. The building provides state-of-the-art clean rooms, general laboratories, wet and dry laboratories for sample preparation, fabrication and analysis. Equipment to synthesize, manipulate, and characterize nanoscale materials and structures is included. The CNMS's major scientific thrusts are in nano-dimensioned soft materials, complex nanophase materials systems, and the crosscutting areas of interfaces and reduced dimensionality that become scientifically critical on the nanoscale. A major focus of the CNMS is to exploit ORNL's unique capabilities in neutron scattering.
- Molecular Foundry:
  The Molecular Foundry at Lawrence Berkeley National Laboratory (LBNL) makes use of existing LBNL facilities such as the Advanced Light Source, the National Center for Electron Microscopy, and the National Energy Research Scientific Computing Center. The facility provides laboratories for materials science, physics, chemistry, biology, and molecular biology. State-of-the-art equipment includes clean rooms, controlled environmental rooms, scanning tunneling microscopes, atomic force microscopes, transmission electron microscope, fluorescence microscopes, mass spectrometers, DNA synthesizer and sequencer, nuclear magnetic resonance spectrometer, ultrahigh vacuum scanning-probe microscopes, photo, uv, and e-beam lithography equipment, peptide synthesizer, advanced preparative and analytical chromatographic equipment, and cell culture facilities.
- Center for Integrated Nanotechnologies (CINT):
  The CINT focuses on exploring the path from scientific discovery to the integration of nanostructures into the micro- and macro-worlds. This path involves experimental and theoretical exploration of behavior, understanding new performance regimes and concepts, testing designs, and integrating nanoscale materials and structures. CINT focus areas are nanophotonics and nanoelectronics, complex functional nanomaterials, nanomechanics, and the nanoscale/bio/microscale interfaces.
- Center for Functional Nanomaterials (CFN):
  The CFN at Brookhaven National Laboratory focuses on understanding the chemical and physical response of nanomaterials to make functional materials such as sensors, activators, and energy-conversion devices. The facility uses existing facilities such as the National Synchrotron Light Source and the Laser Electron Accelerator facility. It also provides clean rooms, general laboratories, and wet and dry laboratories for sample preparation, fabrication, and analysis.
- Center for Nanoscale Materials (CNM):
  The CNM at Argonne National Laboratory focuses on research in advanced magnetic materials, complex oxides, nanophotonics, and bio-inorganic hybrids. The facility uses existing facilities

such as the Advanced Photon Source, the Intense Pulsed Neutron Source, and the Electron Microscopy Center. An x-ray nanoprobe beam line at the Advanced Photon Source is run by the Center for its users.

BER User Facilities

The Biological & Environmental Research program supports the operation of the following national scientific user facilities:

- William R. Wiley Environmental Molecular Sciences Laboratory (EMSL):
  The mission of the EMSL at the Pacific Northwest National Laboratory (PNNL) in Richland, Washington, is to provide integrated experimental and computational resources for discovery and technological innovation in the environmental molecular sciences to support the needs of DOE and the nation. The facilities and capabilities of the EMSL are available to the general scientific and engineering communities to conduct research in the environmental molecular sciences and related areas.
- Joint Genome Institute (JGI):
  The Office of Science / U.S. Department of Energy Joint Genome Institute in Walnut Creek, California, unites the expertise of five national laboratories—Lawrence Berkeley, Lawrence Livermore, Los Alamos, Oak Ridge, and Pacific Northwest—along with the HudsonAlpha Institute for Biotechnology to advance genomics in support of the DOE missions related to clean energy generation and environmental characterization and cleanup. The vast majority of JGI sequencing is conducted under the auspices of the Community Sequencing Program (CSP), surveying the biosphere to characterize organisms relevant to the DOE science mission areas of bioenergy, global carbon cycling, and biogeochemistry.
- Atmospheric Radiation Measurement Climate Research Facility:
  The Atmospheric Radiation Measurement (ARM) Climate Research Facility is a multi-platform national scientific user facility, with instruments at fixed and varying locations around the globe for obtaining continuous field measurements of climate data. The ACRF promotes the advancement of atmospheric process understanding and climate models through precise observations of atmospheric phenomena.

FES User Facilities

The Fusion Energy Sciences program supports the operation of the following national scientific user facilities:

- DIII-D Tokamak Facility:
  DIII-D, located at General Atomics in San Diego, California, is the largest magnetic fusion facility in the U.S. and is operated as a DOE national user facility. DIII-D has been a major contributor to the world fusion program over the past decade in areas of plasma turbulence, energy and particle transport, electron-cyclotron plasma heating and current drive, plasma stability, and boundary layers physics using a “magnetic divertor” to control the magnetic field configuration at the edge of the plasma.
- Alcator C-Mod:
  Alcator C-Mod at the Massachusetts Institute of Technology is operated as a DOE national user facility. Alcator C-Mod is a unique, compact tokamak facility that uses intense magnetic fields to confine high-temperature, high-density plasmas in a small volume. One of its unique features are

the metal (molybdenum) walls to accommodate high power densities. Alcator C-Mod has made significant contributions to the world fusion program in the areas of plasma heating, stability, and confinement of high field tokamaks, which are important integrating issues related to ignition of burning of fusion plasma.

- National Spherical Torus Experiment (NSTX):
  NSTX is an innovative magnetic fusion device that was constructed by the Princeton Plasma Physics Laboratory in collaboration with the Oak Ridge National Laboratory, Columbia University, and the University of Washington at Seattle. It is one of the world's two largest embodiments of the spherical torus confinement concept. NSTX has a unique, nearly spherical plasma shape that provides a test of the theory of toroidal magnetic confinement as the spherical limit is approached. Plasmas in spherical torii have been predicted to be stable even when high ratios of plasma-to-magnetic pressure and self-driven current fraction exist simultaneously in the presence of a nearby conducting wall bounding the plasma. If these predictions are verified, it would indicate that spherical torii use applied magnetic fields more efficiently than most other magnetic confinement systems and could, therefore, be expected to lead to more cost-effective fusion power systems in the long term.

HEP User Facilities

The High Energy Physics program supports the operation of the following national scientific user facilities:

Proton Accelerator Complex

The Proton Accelerator Complex at Fermi National Accelerator Laboratory is composed of the accelerator complex and several experiments—both actual and proposed--that utilize its protons. The complex currently operates two proton beams that are used to generate neutrinos for short and long baseline neutrino experiments.

Booster Neutrino Beam**:** The Booster accelerator is a ring 1500 feet in circumference that receives 400 MeV protons from the linac and accelerates them to 8 GeV. These protons then strike a 71-cm long beryllium target used to generate an intense muon neutrino beam used for two short baseline neutrino oscillation experiments, one currently operating, the other planned.

Neutrinos at the Main Injector (NuMI)**:** The Main Injector takes the 8 GeV protons from the Booster and accelerates them to approximately 150 GeV. As in the Booster, these highly energetic protons strike a target—in this case a carbon target—to generate muons that subsequently decay to muon neutrinos. The result is the most intense neutrino beam in the world. The muon neutrino beam is used for studies of both the disappearance of muon neutrinos and the appearance of non-muon neutrinos such as electron and tau neutrinos.

Facility for Advanced Accelerator Experimental Tests (FACET)

FACET is a 23 GeV electron-beam driven plasma wakefield accelerator test facility located at SLAC National Accelerator Laboratory. It has been optimized for tests of plasma wakefield acceleration with high energy beams of electrons or positrons with short duration pulses. It is open to all users that need such beams with access based on peer review of annually solicited proposals.

NP User Facilities

The Nuclear Physics program supports the operation of the following national scientific user facilities:

- Relativistic Heavy Ion Collider (RHIC):
  RHIC at Brookhaven National Laboratory is a world-class scientific research facility that began operation in 2000, following 10 years of development and construction. Hundreds of physicists from around the world use RHIC to study what the universe may have looked like in the first few moments after its creation. RHIC drives two intersecting beams of gold ions head-on, in a subatomic collision. What physicists learn from these collisions may help us understand more about why the physical world works the way it does, from the smallest subatomic particles, to the largest stars.
- Continuous Electron Beam Accelerator Facility (CEBAF):
  The CEBAF at the Thomas Jefferson National Accelerator Facility, is a world-leading facility in the experimental study of hadronic matter. Based on superconducting radio-frequency (SRF) accelerating technology, CEBAF is the world's most advanced particle accelerator for investigating the quark structure of the atom's nucleus. To probe nuclei, scientists use continuous beams of high-energy electrons from CEBAF.
- Argonne Tandem Linear Accelerator System (ATLAS):
  ATLAS is a national user facility at Argonne National Laboratory in Argonne, Illinois. The ATLAS facility is a leading facility for nuclear structure research in the United States. It provides a wide range of beams for nuclear reaction and structure research to a large community of users from the US and abroad. About 20% of the beam-time is used to generate secondary radioactive beams. These beams are used mostly to study nuclear reactions of astrophysical interest and for nuclear structure investigations. Beam lines are also available for experiments where Users bring their own equipment.