## Science

### Proposed Appropriation Language

For Department of Energy expenses including the purchase, construction and acquisition of plant and capital equipment, and other expenses necessary for science activities in carrying out the purposes of the Department of Energy Organization Act (42 U.S.C. 7101 et seq.), including the acquisition or condemnation of any real property or facility or for plant or facility acquisition, construction, or expansion, and purchase of not to exceed [49] *50* passenger motor vehicles for replacement only, including one law enforcement vehicle, [one ambulance,] *two ambulances*, and three buses, [$4,772,636,000,] *$4,941,682,000*, to remain available until expended [: Provided, That, of the amount appropriated in this paragraph, $93,686,593 shall be used for projects specified in the table that appears under the heading "Congressionally Directed Science Projects" in the text and table under this heading in the explanatory statement described in section 4 (in the matter preceding division A of this consolidated Act)]. *(Energy and Water Development and Related Agencies Appropriations Act, 2009.)*

### Explanation of Change

Changes are proposed to reflect the FY 2010 funding and vehicle request.

# Office of Science

## Overview

## Appropriation Summary by Program

| | (dollars in thousands) | | | |
|---|---|---|---|---|
| | FY 2008 Current Appropriation | FY 2009 Original Appropriation | FY 2009 Additional Appropriation[a] | FY 2010 Request |
| Office of Science | | | | |
| Basic Energy Sciences | 1,252,756[b] | 1,571,972 | +555,406 | 1,685,500 |
| Advanced Scientific Computing Research | 341,774 | 368,820 | +157,110 | 409,000 |
| Biological and Environmental Research | 531,063 | 601,540 | +165,653 | 604,182 |
| High Energy Physics | 702,845[b] | 795,726 | +232,390 | 819,000 |
| Nuclear Physics | 423,671[b] | 512,080 | +154,800 | 552,000 |
| Fusion Energy Sciences | 294,933[b] | 402,550 | +91,023 | 421,000 |
| Science Laboratories Infrastructure | 66,861 | 145,380 | +198,114 | 133,600 |
| Science Program Direction | 177,779 | 186,695 | +1,600 | 213,722 |
| Workforce Development for Teachers and Scientists | 8,044 | 13,583 | +12,500 | 20,678 |
| Safeguards and Security | 75,946 | 80,603 | — | 83,000 |
| Small Business Innovation Research (SBIR)/Small Business Technology Transfer (STTR) (SC funding) | 92,997[bc] | — | +19,004 | — |
| Subtotal, Office of Science | 3,968,669[b] | 4,678,949 | +1,587,600 | 4,941,682 |
| Congressionally-directed projects | 120,161 | 93,687 | — | — |
| Unallocated Recovery Act funding | — | — | +12,400 | — |
| SBIR/STTR (Other DOE funding) | 47,241[d] | — | — | — |
| Subtotal, Office of Science | 4,136,071[b] | 4,772,636 | +1,600,000 | 4,941,682 |
| Coralville, Iowa project rescission | -44,569 | — | — | — |
| Less security charge for reimbursable work | -5,605 | — | — | — |
| Use of prior year balances | -3,014 | -15,000 | — | — |
| Total, Office of Science | 4,082,883[b] | 4,757,636 | +1,600,000 | 4,941,682 |
| Advanced Research Projects Agency-Energy (ARPA-E) | — | 15,000 | — | — |
| Total, Science Appropriation | 4,082,883[b] | 4,772,636 | +1,600,000 | 4,941,682 |

[a] The Additional Appropriations column reflects the planned allocation of funding from the American Recovery and Reinvestment Act of 2009, P.L. 111–5. See the Department of Energy Recovery website at http://www.energy.gov/recovery for up-to-date information regarding Recovery Act funding.
[b] Includes $62,500,000 provided by the Supplemental Appropriations Act, 2008, P.L. 110–252, as follows: Basic Energy Sciences $13,500,000; High Energy Physics $32,000,000; Nuclear Physics $1,500,000; and Fusion Energy Sciences $15,500,000.
[c] Reflects funding reprogrammed within the Science total to support the SBIR and STTR programs.
[d] Reflects funding transferred from other DOE appropriation accounts to support the SBIR and STTR programs.

The Office of Science request for Fiscal Year (FY) 2010 is $4,941,682,000, an increase of $184,046,000, or 3.9%, over the FY 2009 appropriation of $4,757,636,000. Excluding Congressionally-directed projects and a reduction for use of prior year balances in FY 2009, the request is an increase of $262,733,000, or 5.6%, over the comparable FY 2009 level of $4,678,949,000.

The mission of the Office of Science is the delivery of scientific discoveries and major scientific tools to transform our understanding of nature and to advance the energy, economic, and national security of the United States. A key strategy for accomplishing this mission and a hallmark of the Office of Science and its predecessors for more than six decades has been the support of fundamental science challenges and projects that are of great scale. The earliest example is the Manhattan Project, created to address a critical national security need during World War II.

Today, the Office of Science continues this tradition by supporting significant major projects and preeminent national scientific user facilities to study the smallest constituents of matter, including some bits like dark matter, which are seen only indirectly by observing their influences; the most fleeting subatomic, atomic, molecular, and chemical transitions; and the atomic structure-function relationships of biological and inorganic materials that make up our observable world—all to transform our understanding nature and to use this new understanding to address the Department of Energy's missions in energy, economic, and national security. Over past two decades, these activities have helped spur the worldwide scientific revolutions in nanotechnology, biotechnology, and high-performance computing. Together, these revolutions provide the practical basis for addressing the Department's missions. Coming late in the $20^{th}$ century, these revolutions are a fitting close to a century that began with the unraveling of the microscopic constituents of matter and the development of quantum mechanics, which describes how and why the very small world behaves differently from our macroscopic world.

Now, at the dawn of the $21^{st}$ century, the Office of Science is called upon again to address critical societal challenges and key missions of the Department of Energy. Today's energy security challenges, coupled with global climate and environmental concerns, call for truly unprecedented levels of activity and dedication by the Office of Science and the scientific communities that it supports. Significant improvements in existing energy technologies are necessary. But, more importantly, developments of new energy technologies are essential. The $20^{th}$ century witnessed revolutionary advances, bringing us remarkable discoveries such as high temperature superconductors, which transmit electricity without resistance, and carbon nanotubes, which combine the strength of steel with the mass of a feather. Both discoveries, though, were partly serendipitous. In the 21st century, we must take charge of the complexity of materials—both biological and inorganic—and replace serendipity with intention. To accomplish this will require sustained investments in exploratory and high-risk research in traditional and emerging disciplines, including the development of new tools and facilities; focused investments in high-priority research areas; and investments that train new generations of scientists and engineers to be leaders in the $21^{st}$ century. The FY 2010 budget supports all three of these investment strategies.

As described in greater detail below, the Office of Science supports large-scale research programs in condensed matter and materials physics; chemistry; biology; climate and environmental sciences; applied mathematics and computational science; high energy physics and nuclear physics; and plasma physics and fusion energy sciences. The Office of Science also provides the nation's researchers with state-of-the-art user facilities—the large machines of modern science. Increasingly, they are first-of-a kind facilities, and they are in the billion-dollar-class range. These facilities offer capabilities that are unmatched anywhere in the world and enable U.S. researchers and industries to remain at the forefront of science, technology, and innovation. They include electron and proton accelerators and colliders for probing matter on scales from the subatomic to the macroscopic; the world's forefront neutron scattering facility and the world's best suite of synchrotron light sources for probing the structure and function of materials; and the world's largest and fastest computational resources devoted to the most challenging societal problems of our time. These facilities also include technologically advanced, large-scale field sites for investigating the effects of clouds on atmospheric radiation; comprehensively equipped nanoscience and molecular science centers; facilities for rapid genome sequencing and integrated environmental molecular sciences; and facilities for investigating the plasma state and its properties for stable fusion systems. Two new Energy Innovation Hubs, described further in the Basic Energy Sciences section below, are proposed in FY 2010; these Hubs will bring together teams of experts from multiple disciplines to focus on two grand challenges in energy: the creation of fuels directly from sunlight without the use of plants or microbes and advanced methods of electrical energy storage.

Today, the Office of Science supports investigators from more than 300 academic institutions and from all of the DOE laboratories. The FY 2010 Budget Request will support about 25,000 Ph.D.'s, graduate students, undergraduates, engineers, and technicians. Approximately 24,000 researchers from universities, national laboratories, industry, and international partners are expected to use the Office of Science scientific user facilities in FY 2010. The FY 2010 Request supports President's plan to increase Federal investment in the sciences and train students and researchers in critical fields, to invest in areas critical to our clean energy future, and to make the U.S. a leader on climate change.

Within the Science appropriation, the Office of Science has ten programs: Basic Energy Sciences (BES), Advanced Scientific Computing Research (ASCR), Biological and Environmental Research (BER), High Energy Physics (HEP), Nuclear Physics (NP), Fusion Energy Sciences (FES), Science Laboratories Infrastructure (SLI), Science Program Direction (SCPD), Workforce Development for Teachers and Scientists (WDTS), and Safeguards and Security (S&S).

The Office of Science is responsible for the oversight of ten of the DOE national laboratories: Ames National Laboratory, Argonne National Laboratory, Brookhaven National Laboratory, Fermi National Accelerator Laboratory, Lawrence Berkeley National Laboratory, Oak Ridge National Laboratory, Pacific Northwest National Laboratory, Princeton Plasma Physics Laboratory, SLAC National Accelerator Laboratory, and Thomas Jefferson National Accelerator Laboratory.

### Program Overview

Basic Energy Sciences supports fundamental research to understand, predict, and ultimately control matter and energy at the electronic, atomic, and molecular levels in order to provide the foundations for new energy technologies and to support other aspects of DOE missions in energy, environment, and national security. BES-supported research disciplines—condensed matter and materials physics, chemistry, geosciences, and aspects of physical biosciences—provide the knowledge base for the control of the physical and chemical transformations of materials and the discovery and design of new materials with novel structures, functions, and properties. These disciplines drive new solutions and technologies in virtually every aspect of energy resources, production, conversion, transmission, storage, efficiency, and waste mitigation. BES also plans, designs, constructs, and operates scientific user facilities that use x-ray, neutron, and electron beam scattering to probe the most fundamental electronic and atomic properties of materials at extreme limits of time, space, and energy resolution. The world-class scientific user facilities supported by BES provide important capabilities for fabricating, characterizing, and transforming materials of all kinds from metals, alloys, and ceramics to fragile bio-inspired and biological materials. In FY 2010, investments continue to support the Energy Frontier Research Centers, focused on accelerating fundamental energy sciences, and single investigator and small groups. BES takes part in the Department's multi-disciplinary Energy Innovation Hubs, which focus on critical science and technology for high-risk, high-reward research to revolutionize how the U.S. produces, distributes, and uses energy. The Hubs will promote energy security and reduce greenhouse gas emissions. They will also strengthen the Nation's economy by coordinating teams of experts from multiple fields to blend technology development, engineering design, and energy policy. Finally, they will develop critical areas of expertise needed for the green economy. Two Energy Innovation Hubs are initiated by BES to focus on Fuels from Sunlight and on Batteries and Energy Storage. The BES Hubs are complimentary to the EFRCs and will assemble multidisciplinary teams from universities, national laboratories, and the private sector to advance state-of-the-art energy sciences and technology toward their fundamental limits in search of revolutionary changes in energy production and use; and will not include construction of buildings. DOE will encourage risk-taking by making the initial grant period five years, renewed thereafter for up to 10 years. Any funding after 10 years would be predicated on "raising the bar" above that needed for simple renewal. BES continues support for the operations of its suite of scientific user facilities and construction of the National Synchrotron Light Source II, and full operations of the Linac Coherent Light Source will begin in FY 2010.

Advanced Scientific Computing Research supports research to discover, develop, and deploy the computational and networking capabilities to analyze, model, simulate, and predict complex phenomena important to DOE. Scientific computing is particularly important for the solution of research problems that are unsolvable through traditional theoretical and experimental approaches or are too hazardous, time-consuming, or expensive to solve by traditional means. ASCR supports research in applied mathematics, computer science, advanced networking, and computational science (Scientific Discovery through Advanced Computing, SciDAC); as well as research and evaluation prototypes, and the operation of high performance computing systems and networks. In FY 2010, ASCR continues research efforts in SciDAC, applied mathematics, and computer science programs. The FY 2010 request supports continued operations of the Leadership Computing Facilities at Oak Ridge National Laboratory and Argonne National Laboratory. The total capacity of the National Energy Research Scientific Computing (NERSC) facility at Lawrence Berkeley National Laboratory will increase from 360 teraflops to approximately one petaflop with the acquisition and operation of NERSC-6. ESnet will deliver 100–400 gigabit per second (Gbs) connections among the Office of Science laboratories in FY 2010 from 40–60 Gbs in FY 2009.

Biological and Environmental Research supports research to explore the frontiers of genome-enabled biology; discover the physical, chemical, and biological drivers of climate change; and seek the molecular determinants of environmental sustainability and stewardship. BER-supported systems biology research uncovers Nature's secrets from the diversity of microbes and plants to understand how biological systems work, how they interact with each other, and how they can be manipulated to harness their processes and products that contribute to new strategies for producing new biofuels, cleaning up legacy waste, and sequestering carbon dioxide ($CO_2$). BER plays a vital role in supporting research on atmospheric processes, climate modeling, interactions between ecosystems and greenhouse gases (especially $CO_2$), and analysis of impacts of climatic change on energy production and use. Subsurface biogeochemistry research seeks to understand the role that subsurface biogeochemical processes play in determining the fate and transport of contaminants including heavy metals and radionuclides. In FY 2010, BER continues research in systems biology, radiochemistry, climate science, and subsurface biogeochemistry. Support is provided for the three DOE Bioenergy Research Centers started in FY 2007, the Joint Genome Institute, and operations of and capital equipment for the Environmental Molecular Science Laboratory. A new activity for climate model visualization is initiated in FY 2010 to develop onsite and remote-access tools for model development and evaluation. BER will also continue support for simulations and analyses needed for part of the Intergovernmental Panel on Climate Change Fifth Assessment.

High Energy Physics program supports research to understand how our universe works at its most fundamental level. This is accomplished by discovering the most elementary constituents of matter and energy, probing the interactions between them, and exploring the basic nature of space and time itself. HEP is focused on three scientific frontiers in particle physics: the Energy Frontier, the Intensity Frontier, and the Cosmic Frontier. Research includes theoretical and experimental studies by individual investigators and large collaborative teams: some who gather and analyze data from accelerator facilities in the U.S. and around the world; and others who develop and deploy ultra-sensitive ground- and space-based instruments to detect particles from space and observe astrophysical phenomena that advance our understanding of fundamental particle properties. HEP also invents new technologies to meet the challenges of research at the frontiers such as superconducting radio frequency technologies. The Tevatron Collider at Fermi National Accelerator Laboratory continues operations during FY 2010. Its record-breaking performance over the last few years means it remains competitive with the Large Hadron Collider (LHC) in Geneva, Switzerland, for significant discoveries. Support for LHC detector operations, maintenance, computing, and R&D continues in FY 2010 in order to maintain a U.S. leadership role in the LHC program. Construction continues for the NuMI Off-Axis Neutrino Appearance (NOνA) project to enable key measurements of neutrino properties. R&D for proposed new experiments using the NuMI beam and other auxiliary beamlines, such as the Long Baseline Neutrino oscillation experiment (LBNE) and the Muon to Electron Experiment (Mu2e), will be underway so these experiments can be ready for operation before the end of the next decade. Several national and international collaborative projects to pursue questions in dark matter, dark energy, and neutrino properties continue in FY 2010, including the Cryogenic Dark Matter Search at the Soudan Mine in Minnesota, the Dark Energy Survey experiment in Chile, and R&D for the Joint Dark Energy Mission, the Large Synoptic Survey Telescope, and R&D efforts for experiments that may be located in the National Science Foundation’s proposed Deep Underground Science and Engineering Laboratory (DUSEL). HEP also continues supported for advanced accelerator and detector R&D and R&D in superconducting radio frequency technology applicable to a variety of future accelerator projects.

Nuclear Physics supports research to discover, explore, and understand all forms of nuclear matter. The fundamental particles that compose nuclear matter, quarks and gluons, are relatively well understood, but exactly how they fit together and interact to create different types of matter in the universe is still largely not understood. To accomplish this, NP supports experimental and theoretical research—along with the development and operation of particle accelerators and advanced technologies—to create, detect, and describe the different forms and complexities of nuclear matter that can exist in the universe, including those that are no longer found naturally. NP also provides stewardship of isotope production and technologies to advance important applications, research, and tools for that nation. The FY 2010 request supports core nuclear physics research at over 85 academic institutions and 9 of the DOE national laboratories. The request supports near optimal levels of operations at NP’s four scientific user facilities: the Continuous Electron Beam Accelerator Facility (CEBAF), the Relativistic Heavy Ion Collider (RHIC), the Argonne Tandem Linac Accelerator System (ATLAS), and the Holifield Radioactive Ion Beam Facility (HRIBF). Construction for the 12 GeV CEBAF Upgrade project continues, as well as conceptual design and R&D for the proposed Facility for Rare Isotope Beams (FRIB). The request also supports several major items of equipment (MIEs) to address compelling scientific opportunities. In FY 2010, the Isotope Development and Production for Research Applications Program will focus on production on the isotope needs of stakeholders and research isotope priorities identified by the Nuclear Science Advisory Committee and community input.

Fusion Energy Sciences supports research to expand the fundamental understanding of matter at very high temperatures and densities and the scientific foundations needed to develop a fusion energy source. This is accomplished by studying plasmas under a wide range of temperature and density, developing advanced diagnostics to make detailed measurements of their properties, and creating theoretical/computational models to resolve the essential physics. FES operates scientific user facilities to enable world-leading research programs in high-temperature, magnetically confined plasmas, and to participate in the design and construction of ITER, the world's first facility for studying a sustained burning plasma. FES also supports enabling R&D to improve the components and systems that are used to build fusion facilities. The FY 2010 budget request funds the U.S Contributions to ITER project, including research and development of key components, long-lead procurements, personnel, and cash contribution to the ITER Organization. Research at the major experimental facilities in the FES program—the DIII-D tokamak, the Alcator C-Mod tokamak, and the National Spherical Torus Experiment (NSTX)—will continue to focus on providing solutions to key high-priority ITER issues and build a firm physics basis for ITER design and operation. The FY 2010 request will continue support for the Fusion Simulation Program computational initiative and the research at two plasma science centers selected in FY 2009. FES also continues to support the joint program in high energy density laboratory plasmas (HEDLP) with the National Nuclear Security Administration.

Workforce Development for Teachers and Scientists supports a range of opportunities to the Nation's science, mathematics, engineering, and technology (STEM) students and educators that will help the U.S. maintain its competitive edge. These opportunities help inspire students to pursue STEM fields of study and aim to increase the pipeline of skilled scientists and engineers who can successfully pursue careers in areas that will support the development of a sustainable, clean energy future; support our national security; and contribute to U.S scientific discovery and innovation. WDTS supports programs that place undergraduate students into world class research environments to improve their content knowledge and to help them understand how to be successful as researchers and teachers of STEM fields. WDTS also supports professional development experiences for K-12 and undergraduate faculty who teach STEM subjects by providing them with mentor-intensive research experiences that teach them not only content knowledge, but also how to translate lessons learned in the laboratory into classroom practice. WDTS also supports competitions at the middle school and high school levels, such as the National Science Bowl®, that are designed to reward and recognize high-potential science and engineering students. In addition to supporting these core activities, WDTS will continue an Office of Science graduate fellowship program in FY 2010.This program was initiated with the Recovery Act funds. The graduate fellowships will be competitively awarded and will provide support for three years to graduate students pursuing advanced science and engineering degrees with an interest in energy, environment, and basic research.

### High-Risk, High-Return Research[a]

The Office of Science programs incorporate high-risk, high-return research elements in all of its research portfolios. Because advancing the frontiers of science also depends on the continued availability of state-of-the-art scientific facilities, the Office of Science constructs and operates national scientific facilities and instruments that comprise the world's most sophisticated suite of research capabilities.

Effective program management is critical to the support of high-risk, high-return research. The Office of Science program managers are experts in their respective fields and communicate program research priorities and interests to the scientific community; select proposal reviewers that are open to bold ideas; provide guidance to merit reviewers—including guidance on consideration of high-risk, high-return research; and make recommendations on proposal selection, weighing inputs from peer review with programmatic relevance, potential impact, and overall portfolio balance. Committees of Visitors review

[a] In compliance with reporting requirements in America COMPETES (P.L. 110–69, section 1008).

program portfolios triennially to assess, among other things, the balance and impact of the portfolios, including an assessment of high-risk, high-return research.

The fraction of high-risk, high-return activities is not easy to quantify, because such research is integrated within program portfolios. However, several mechanisms are used to identify and develop the “high-return” research topics, including Federal advisory committees, program and topical workshops, interagency working groups, National Academy of Sciences (NAS) studies, and special Office of Science Program solicitations. The results of these activities have identified opportunities for new, compelling research. As examples, some of these opportunities are captured in the following reports: *New Frontiers of Science in Radiochemistry and Instrumentation for Radionuclide Imaging* workshop report (2009); *New Science for a Secure Energy Future*, by the Basic Energy Sciences Advisory Committee (2008); *Identifying Outstanding Grand Challenges in Climate Change Research* workshop report (2008); *The Potential Impact of High-End Capability Computing (HECC) on Four Illustrative Fields of Science and Engineering*, by the National Research Council (2008); and *The Frontiers of Nuclear Science*, by the Nuclear Sciences Advisory Committee (2007).

**Basic & Applied R&D Coordination**

Coordination between the Department’s basic research and applied technology programs is a high priority for the Secretary of Energy. The Department has a responsibility to coordinate its basic and applied research programs in headquarters to enable effective basic-applied R&D integration by the science and technology communities (e.g., national laboratories, universities, and private companies) that support the DOE mission. Office of Science efforts have focused on improving communication and collaboration between federal program managers and within the S&T communities, and increasing opportunities for collaborative research efforts targeted towards the interface of scientific research and technology development to ultimately accelerate DOE mission and national goals.

The Office of Science coordinates its basic research efforts with the Department’s applied technology offices by using scientific and technical workshops; structured targeted research efforts driven by program manager-level coordination between the basic and applied R&D programs; joint program planning or joint program reviews; jointly funded or jointly coordinated solicitations; shared grantee/contractor meetings and conferences to bring the research communities together; and portfolio assessment efforts by structured working groups guided by DOE senior management.

Coordination between the basic and applied programs is also enhanced through joint programs, jointly-funded scientific facilities, and the program management activities of the DOE Small Business Innovation Research (SBIR) and Small Business Technology Research Programs (STTR). Additionally, co-funding research activities and facilities at the DOE laboratories and funding mechanisms that encourage broad partnerships (e.g., the Funding Opportunity Announcement) are also means by which the Office of Science facilitates greater communication and research integration within the S&T communities.

The Office of Sciences has engaged in on-going and productive coordination efforts with the DOE applied technology programs over the past decade in a number of research areas including, but not limited to biofuels derived from biomass; solar energy utilization; hydrogen production, storage, and use; building technologies, including solid-state lighting; advanced fuel cycle technologies; vehicle technologies; and improving efficiencies in industrial processes. Over the past couple of years, basic-applied R&D coordination efforts have increased in the areas of carbon dioxide capture and storage, characterization of radioactive waste, catalysis, materials under extreme conditions, electrical energy storage for transportation and grid-level storage, high energy density laboratory plasmas, production of radioactive and stable isotopes, and applied mathematics for optimization of complex systems such as fossil fuel power generation, the nuclear fuel cycle, and power grid control and grid modernization.

**SC Funding for Selected Administration Priorities**

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| President's Plan for Science and Innovation | 4,082,883 | 4,757,636 | 4,941,682 |
| Climate Change Science Program | 128,191 | 167,810 | 165,288 |
| Climate Change Technology Program | 511,669 | 620,253 | 638,717 |
| Networking and Information Technology Research and Development | 371,353 | 399,521 | 446,988 |
| National Nanotechnology Initiative | 193,902 | 299,964 | 326,542 |

### President's Plan for Science and Innovation

The President's Plan for Science and Innovation encompasses the entire Office of Science budget, as part of a strategy to double overall basic research funding at select agencies over 10 years.

### Climate Change Research

U.S. Climate Change Research is currently organized into the Climate Change Science Program (CCSP) and the Climate Change Technology Program (CCTP). The CCSP includes the interagency U.S. Global Change Research Program (USGCRP), proposed by the first President Bush in 1989 and codified by Congress in the Global Change Research Act of 1990 (P.L. 101–606).

- **Climate Change Science Program**: The BER Climate and Environmental Sciences subprogram (excluding the Climate Change Mitigation element which focuses on carbon sequestration in the terrestrial biosphere and activities transferred from the former Environmental Remediation subprogram) represents DOE's contribution to the CCSP. SC investments supported under the Climate Change Science Program in global and regional climate modeling, combined with measurement and observational experiments, can improve understanding of global carbon cycling and impacts, inform carbon management strategies, and help plan for future energy resource needs.
- **Climate Change Technology Program**: In support of the U.S. Climate Change Technology Program, the Department of Energy analyzed its energy technology portfolio across program areas to determine what actions could be taken to reduce greenhouse gas emission (GHG) intensities. The technical planning goal for this analysis was to develop a portfolio of technology options that, if deployed worldwide, could put global GHG emissions on a trajectory to achieve atmospheric concentrations of carbon between 450 to 550 parts per million (ppm). Programs were selected for the new climate change technology portfolio based on their potential to reduce carbon (in billions of tons of carbon) emissions into the atmosphere between FY 2015–2100.

### Networking and Information Technology Research and Development

SC computing activities (including high-end computing infrastructure, applications, and R&D; large scale networking activities; and the Computational Sciences Graduate Fellowship) are coordinated with other Federal efforts through the National Information Technology Research and Development (NITRD) subcommittee of the National Science and Technology Council and its Technology Committee. The

NITRD Subcommittee provides active coordination for the multiagency NITRD Program. The Subcommittee is made up of representatives from each of the participating NITRD agencies and from OMB, OSTP, and the National Coordination Office for IT R&D.

### National Nanotechnology Initiative

Research programs and facilities supported by SC are the predominant DOE components of the National Nanotechnology Initiative, which is coordinated across the Federal government by the Nanoscale Science, Engineering, and Technology Subcommittee under the Committee on Technology of the National Science and Technology Council. The SC investment in FY 2010 continues to support full operation of the five Nanoscale Science Research Center user facilities and an extensive array of individual university grants and laboratory research programs. The Energy Frontier Research Centers, larger collaborative efforts in which a portion of the activity relates to nanoscale science, are also continued. Nanoscience funding increases are due partly to small increases across all of these mechanisms, which include activities related to solar energy conversion, chemical imaging, nuclear energy, ultrafast science, instrumentation for characterization, and other areas. However, much of the increase in FY 2010 results from the initiation of Energy Innovation Hubs focusing on electrical energy storage and solar fuels, in which it is anticipated that a fraction of the activity will be appropriately characterized as nanoscience.

### Energy Innovation Hubs

SC takes part in the Department's multi-disciplinary Energy Innovation Hubs, which focus on critical science and technology for high-risk, high-reward research to revolutionize how the U.S. produces, distributes, and uses energy. The Hubs will promote energy security and reduce greenhouse gas emissions. They will also strengthen the Nation's economy by coordinating teams of experts from multiple fields to blend technology development, engineering design, and energy policy. Finally, they will develop the critical areas of expertise needed for the green economy.

The Hubs support the Secretary of Energy's goal to improve coordination between basic and applied research and technology development and engineering design, and will include teams of experts from multiple disciplines and blend basic scientific research, technology development, engineering design, and energy policy to create an energy portfolio that is efficient and scalable in a timely manner. Basic Energy Sciences will support two Hubs, one focused on Fuels from Sunlight and one on Batteries and Energy Storage. Similar to the DOE Bioenergy Research Centers; universities, national labs, and the private sector—or partnerships among those groups—will be eligible to apply. Proposals will be selected based on external merit review and awards will provide support for research activities, not construction of new buildings. DOE will encourage risk-taking by making the initial grant period five years, renewed thereafter for up to 10 years. Any funding after 10 years would be predicated on "raising the bar" above that needed for simple renewal.

### Regaining ENERGY Science and Engineering Edge (RE-ENERGYSE)

The Department is undertaking a broad educational effort that cuts across program offices to inspire students and workers to pursue careers in science, engineering, and entrepreneurship related to clean energy and other fields important to the Department's mission. RE-ENERGYSE is a new initiative to focus on a number of critical areas that will build the foundation of a vibrant American workforce to participate in the green economy and advance science and innovation in the U.S. SC is supporting the initiative with a new graduate fellowship program ($5,000,000 requested in WDTS) that will support 50–60 U.S. students pursing advanced degrees in SC mission-relevant fields.

### Scientific Workforce

Workforce development is an important element of the Office of Science mission to help ensure a science-trained workforce, including researchers, engineers, science educators, and technicians. The research programs and projects at the national laboratories, universities, and research institutes actively integrate undergraduate and graduate students and post-doctoral investigators into their work. This "hands-on" approach is important for the development of the next generation of scientists, engineers, and science educators.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| Estimated Number of University Grants | | | |
| BES | 1,000 | 1,200 | 1,300 |
| ASCR | 211 | 224 | 260 |
| BER | 447 | 480 | 475 |
| HEP | 200 | 200 | 200 |
| NP | 184 | 190 | 200 |
| FES | 246 | 236 | 246 |
| Total, Estimated Number of University Grants | 2,288 | 2,530 | 2,681 |
| Estimated Number of Ph.D.s Supported | | | |
| BES | 4,610 | 5,840 | 6,300 |
| ASCR | 698 | 735 | 766 |
| BER | 1,624 | 1,820 | 1,795 |
| HEP | 1,660 | 1,685 | 1,690 |
| NP | 1,098 | 1,040 | 1,110 |
| FES | 835 | 832 | 836 |
| Total, Estimated Number of Ph.D.s Supported | 10,525 | 11,952 | 12,497 |
| Estimated Number of Graduate Students Supported | | | |
| BES | 1,490 | 2,000 | 2,200 |
| ASCR | 495 | 533 | 563 |
| BER | 429 | 485 | 480 |
| HEP | 585 | 595 | 595 |
| NP | 493 | 490 | 510 |
| FES | 326 | 325 | 327 |
| Total, Estimated Number of Graduate Students Supported | 3,818 | 4,428 | 4,675 |

## Mission Readiness of Office of Science Laboratories

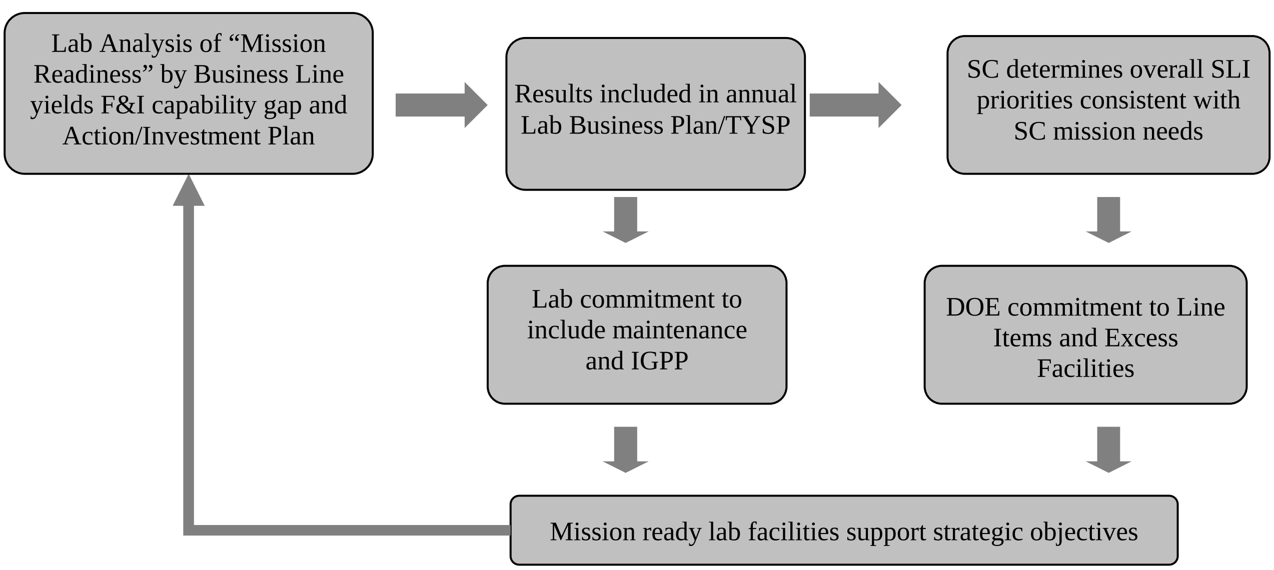
The mission readiness of a laboratory's facilities and infrastructure is the capability of those assets to enable delivery of the scientific mission assigned to that laboratory. Ensuring continued mission readiness into the future is the focus of the SC Facilities and Infrastructure program.

The infrastructure of the Office of Science's national laboratories is aging, with nearly half of active facility space 40 years old or older. Despite past investments, many laboratory facilities and utility systems are not adequate to support the scientific mission in the future because they do not meet the requirements of a modern research facility. The Infrastructure Modernization Initiative includes a portfolio of projects funded through the SLI budget that will provide modern laboratory space, renovate space that does not meet research needs, replace facilities that are no longer cost effective to renovate or operate, modernize utility systems to prevent failures and ensure efficiency, and/or remove excess facilities to allow safe and efficient operations. These investments will revitalize SC's ten laboratories over the next ten years.

In order to evaluate current and projected future mission readiness, SC laboratories are implementing a new Mission Readiness Assessment Process. This process (see below) assures that facility and infrastructure investments support SC scientific mission goals, and serves as the basis of the infrastructure strategy described in the SC Annual Laboratory Plans.

**Mission Readiness Assessment Process**

Driven by Science—executed through budget and contract commitments




The process results in core capability gap analyses and needed investments via DOE capital line item investments or other means. The resulting facilities and infrastructure strategies are provided within the Annual Laboratory Plans using standardized tables. This process is also consistent with recommendations of the National Research Council in their 2004 Report, "Intelligent Sustainment and Renewal of Department of Energy Facilities and Infrastructure".

The Annual Laboratory Plans prepared in 2008 incorporated the basic components of the Mission Readiness protocols by specifically tying proposed future investments to laboratory business lines. Since that time, all ten SC laboratories have begun full implementation of the Mission Readiness Assessment

Process. As implementation moves forward, peer reviews of each laboratory's Mission Readiness Assessment Process are being coordinated and implemented to provide verification that the process is being appropriately implemented.

The investments will not only improve SC's mission readiness but will also reduce SC's deferred maintenance backlog thereby improving SC's overall Asset Condition Index.

### Contractor Pension Plan Funding

Funding is requested to reimburse the costs of DOE contractor contributions to defined-benefit pension plans as required by the Employee Retirement Income Security Act (ERISA), as amended by the Pension Protection Act of 2006, and consistent with Departmental direction. The Pension Protection Act amended ERISA to require accelerated funding of defined benefit pension plans so that the plans become 100% funded in 2011. Most contractors that manage and operate DOE's laboratories are contractually required to assume sponsorship of any existing contractor defined benefit pension plans for incumbent employees who work and retire from these sites and facilities. Increased contributions began to be required for some of these plans as a result of the downturn in investment values in FY 2009. Whether additional funding will be needed in future years will depend on the funded status of the plans based on plan investment portfolios managed by the contractors as sponsors of the plans.

### Strategic Themes and Goals and GPRA Unit Program Goals

The Department's Strategic Plan identifies five Strategic Themes (one each for nuclear, energy, science, management, and environmental aspects of the mission) plus 16 Strategic Goals that tie to the Strategic Themes. The Office of Science (SC) supports the following goals:

Strategic Theme 3, Scientific Discovery and Innovation: Strengthening U.S. scientific discovery, economic competitiveness, and improving quality of life through innovations in science and technology.

- Strategic Goal 3.1, Scientific Breakthroughs: Achieve the major scientific discoveries that will drive U.S. competitiveness; inspire America; and revolutionize our approaches to the Nation's energy, national security, and environmental quality challenges.
- Strategic Goal 3.2, Foundations of Science: Deliver the scientific facilities, train the next generation of scientists and engineers, and provide the laboratory capabilities and infrastructure required for U.S. scientific primacy.

The programs funded by the Science appropriation have the following six Government Performance and Results Act (GPRA) Unit Program Goals:

- GPRA Unit Program Goal 3.1/2.50.00: Advance the Basic Science for Energy Independence—Provide the scientific knowledge and tools to achieve energy independence, securing U.S. leadership and essential breakthroughs in basic energy sciences.
- GPRA Unit Program Goal 3.1/2.51.00: Deliver Computing for Accelerated Progress in Science—Deliver forefront computational and networking capabilities to scientists nationwide that enable them to extend the frontiers of science, answering critical questions that range from the function of living cells to the power of fusion energy.
- GPRA Unit Program Goal 3.1/2.48.00: Harness the Power of Our Living World—Provide the biological and environmental discoveries necessary to clean and protect our environment, offer new energy alternatives, and fundamentally change the nature of medical care to improve human health.
- GPRA Unit Program Goal 3.1/2.46.00: Explore the Fundamental Interactions of Energy, Matter, Time, and Space—Understand the unification of fundamental particles and forces and the mysterious

forms of unseen energy and matter that dominate the universe, search for possible new dimensions of space, and investigate the nature of time itself.

- GPRA Unit Program Goal 3.1/2.47.00: Explore Nuclear Matter, from Quarks to Stars—Understand the evolution and structure of nuclear matter, from the smallest building blocks, quarks, and gluons; to the stable elements in the Universe created by stars; to unique isotopes created in the laboratory that exist at the limits of stability and possess radically different properties from known matter.
- GPRA Unit Program Goal 3.1/2.49.00: Bring the Power of the Stars to Earth—Answer the key scientific questions and overcome enormous technical challenges to harness the power that fuels our sun.

**Contribution to Strategic Goals**

Six of the programs within the Science appropriation directly contribute to Strategic Goals 3.1 and 3.2: Basic Energy Sciences, Advanced Scientific Computing Research, Biological and Environmental Research, High Energy Physics, Nuclear Physics, and Fusion Energy Sciences.

**Means and Strategies**

Each of the six SC programs support fundamental, innovative, peer-reviewed research to create new knowledge in areas important to SC and program missions, and support the design, construction, and operation of a wide array of scientific user facilities essential for advancing the frontiers of research in relevant areas of science and technology and providing the Nation scientific tools to remain at the forefront of innovation and competitiveness. All research projects and facilities undergo regular peer review and merit evaluation based on procedures set down in 10 CFR 605 for the extramural grant program and under a similar process for the laboratory programs and scientific user facilities. All new projects are selected through peer review and merit evaluation.

SC programs ensure effective management processes for cost-effective investments and timely delivery of projects. SC programs utilize input from the scientific community to ensure progress is made and opportunities are identified. Programs also form mutually beneficial partnerships with programs sharing common goals. The basic science supported by each SC program is coordinated with the activities of other programs within SC, with programs of the DOE applied technology offices and the National Nuclear Security Administration, and with programs of other Federal agencies. SC also promotes the transfer of the results of its basic research to contribute to DOE missions in areas of energy, environment, and national security. Program-specific means and strategies are described in detail in the individual program budget narrative sections under “Program Planning and Management.”

External factors, in addition to budgetary constraints, that affect the level of performance include changing mission needs as described by the DOE and SC mission statements and strategic plans; evolving scientific opportunities as determined, in part, by scientific workshops and proposals received by researchers; results of external program reviews and international benchmarking activities of entire fields or sub-fields, such as those performed by the National Academy of Sciences; unanticipated failures in critical components of scientific user facilities or major research programs; and strategic and programmatic decisions made by non-DOE funded domestic research activities and by major international research and technology entities.

**Validation and Verification**

Progress against established plans is evaluated by periodic internal and external performance reviews. These reviews provide an opportunity to verify and validate performance. Monthly, quarterly, semiannual, and annual reviews consistent with specific program management plans are performed to ensure technical progress, cost and schedule adherence, and responsiveness to program requirements

## Office of Science

## Funding by Site by Program

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Ames Laboratory | | | |
| Basic Energy Sciences | 19,981 | 20,423 | 21,126 |
| Advanced Scientific Computing Research | 1,466 | 1,472 | 600 |
| Biological and Environmental Research | 500 | 500 | — |
| Workforce Development for Teachers and Scientists | 220 | 415 | 541 |
| Safeguards and Security | 944 | 974 | 980 |
| Total, Ames Laboratory | 23,111 | 23,784 | 23,247 |
| | | | |
| Ames Site Office | | | |
| Science Program Direction | 587 | 600 | 618 |
| | | | |
| Argonne National Laboratory | | | |
| Basic Energy Sciences | 183,637 | 182,130 | 193,534 |
| Advanced Scientific Computing Research | 43,970 | 41,664 | 54,528 |
| Biological and Environmental Research | 27,040 | 27,937 | 29,247 |
| High Energy Physics | 13,335 | 12,856 | 11,003 |
| Nuclear Physics | 26,121 | 27,056 | 28,708 |
| Fusion Energy Sciences | 83 | 40 | 40 |
| Science Laboratories Infrastructure | 389 | — | 10,000 |
| Workforce Development for Teachers and Scientists | 1,155 | 825 | 964 |
| Safeguards and Security | 8,562 | 8,514 | 8,694 |
| Total, Argonne National Laboratory | 304,292 | 301,022 | 336,718 |
| | | | |
| Argonne Site Office | | | |
| Science Program Direction | 4,201 | 3,928 | 4,299 |
| | | | |
| Berkeley Site Office | | | |
| Science Program Direction | 4,644 | 3,962 | 4,567 |

| (dollars in thousands) | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| Brookhaven National Laboratory | | | |
| Basic Energy Sciences | 137,216 | 195,531 | 236,804 |
| Advanced Scientific Computing Research | 730 | 390 | 200 |
| Biological and Environmental Research | 20,145 | 19,433 | 18,869 |
| High Energy Physics | 46,701 | 43,314 | 24,796 |
| Nuclear Physics | 169,467 | 179,694 | 187,593 |
| Science Laboratories Infrastructure | 8,200 | 14,882 | 46,387 |
| Workforce Development for Teachers and Scientists | 575 | 825 | 1,050 |
| Safeguards and Security | 10,859 | 11,349 | 11,530 |
| Total, Brookhaven National Laboratory | 393,893 | 465,418 | 527,229 |
| | | | |
| Brookhaven Site Office | | | |
| Science Program Direction | 4,295 | 3,714 | 5,436 |
| | | | |
| Chicago Office | | | |
| Basic Energy Sciences | 190,427 | 178,280 | 175,159 |
| Advanced Scientific Computing Research | 57,143 | 52,626 | 51,492 |
| Biological and Environmental Research | 151,467 | 142,895 | 96,199 |
| High Energy Physics | 129,168 | 133,966 | 130,059 |
| Nuclear Physics | 67,119 | 65,429 | 69,568 |
| Fusion Energy Sciences | 146,519 | 146,049 | 147,144 |
| Science Laboratories Infrastructure | 1,506 | — | — |
| Science Program Direction | 26,716 | 26,837 | 33,600 |
| Workforce Development for Teachers and Scientists | 15 | — | — |
| Safeguards and Security | 1,992 | 1,600 | — |
| Congressionally Directed Projects | 111,612 | 69,676 | — |
| SBIR/STTR | 140,238 | — | — |
| Total, Chicago Office | 1,023,922 | 817,358 | 703,221 |

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Fermi National Accelerator Laboratory | | | |
| Advanced Scientific Computing Research | 270 | 360 | 260 |
| High Energy Physics | 351,484 | 374,449 | 398,872 |
| Nuclear Physics | 560 | 292 | — |
| Workforce Development for Teachers and Scientists | 170 | 240 | 420 |
| Safeguards and Security | 2,201 | 1,734 | 3,383 |
| Total, Fermi National Accelerator Laboratory | 354,685 | 377,075 | 402,935 |
| | | | |
| Fermi Site Office | | | |
| Science Program Direction | 2,512 | 2,416 | 2,695 |
| | | | |
| Golden Field Office | | | |
| Workforce Development for Teachers and Scientists | 655 | 523 | 880 |
| | | | |
| Idaho National Laboratory | | | |
| Basic Energy Sciences | 407 | 214 | 221 |
| Biological and Environmental Research | 1,703 | 1,885 | 1,717 |
| Fusion Energy Sciences | 2,371 | 2,222 | 2,222 |
| Workforce Development for Teachers and Scientists | 86 | 79 | 140 |
| Total, Idaho National Laboratory | 4,567 | 4,400 | 4,300 |
| | | | |
| Lawrence Berkeley National Laboratory | | | |
| Basic Energy Sciences | 131,469 | 138,691 | 131,529 |
| Advanced Scientific Computing Research | 101,594 | 89,786 | 96,178 |
| Biological and Environmental Research | 110,688 | 104,248 | 119,490 |
| High Energy Physics | 53,412 | 59,988 | 46,142 |
| Nuclear Physics | 24,756 | 25,498 | 33,340 |
| Fusion Energy Sciences | 4,796 | 4,856 | 4,856 |
| Science Laboratories Infrastructure | 17,417 | 29,956 | 34,027 |
| Workforce Development for Teachers and Scientists | 635 | 686 | 897 |
| Safeguards and Security | 4,985 | 5,006 | 5,059 |
| Total, Lawrence Berkeley National Laboratory | 449,752 | 458,715 | 471,518 |

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Lawrence Livermore National Laboratory | | | |
| Basic Energy Sciences | 4,071 | 3,270 | 3,387 |
| Advanced Scientific Computing Research | 16,631 | 11,748 | 11,305 |
| Biological and Environmental Research | 23,903 | 23,162 | 13,898 |
| High Energy Physics | 560 | 795 | 788 |
| Nuclear Physics | 1,509 | 1,575 | 1,022 |
| Fusion Energy Sciences | 13,150 | 12,534 | 12,538 |
| Workforce Development for Teachers and Scientists | 17 | 83 | 345 |
| Total, Lawrence Livermore National Laboratory | 59,841 | 53,167 | 43,283 |
| | | | |
| Los Alamos National Laboratory | | | |
| Basic Energy Sciences | 29,304 | 32,608 | 33,148 |
| Advanced Scientific Computing Research | 4,248 | 3,420 | 2,470 |
| Biological and Environmental Research | 19,709 | 17,770 | 10,303 |
| High Energy Physics | 423 | 248 | 248 |
| Nuclear Physics | 11,769 | 17,168 | 18,221 |
| Fusion Energy Sciences | 3,612 | 2,981 | 3,399 |
| Workforce Development for Teachers and Scientists | 50 | 210 | 345 |
| Total, Los Alamos National Laboratory | 69,115 | 74,405 | 68,134 |
| | | | |
| National Energy Technology Laboratory | | | |
| Basic Energy Sciences | 300 | — | — |
| Workforce Development for Teachers and Scientists | 589 | 734 | 857 |
| Total, National Energy Technology Laboratory | 889 | 734 | 857 |
| | | | |
| National Renewable Energy Laboratory | | | |
| Basic Energy Sciences | 7,171 | 5,773 | 5,980 |
| Advanced Scientific Computing Research | 796 | 581 | 372 |
| Biological and Environmental Research | 1,438 | 1,497 | 1,136 |
| Workforce Development for Teachers and Scientists | 35 | 50 | 50 |
| Total, National Renewable Energy Laboratory | 9,440 | 7,901 | 7,538 |
| | | | |
| New Brunswick Laboratory | | | |
| Science Program Direction | 6,644 | 6,583 | 6,981 |

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Oak Ridge Institute for Science and Education | | | |
| Basic Energy Sciences | 2,060 | 1,600 | 1,600 |
| Advanced Scientific Computing Research | 1,082 | 1,000 | — |
| Biological and Environmental Research | 5,342 | 4,396 | 4,053 |
| High Energy Physics | 304 | 400 | 250 |
| Nuclear Physics | 1,228 | 1,238 | 703 |
| Fusion Energy Sciences | 1,631 | 1,748 | 1,400 |
| Workforce Development for Teachers and Scientists | 2,250 | 3,506 | 3,604 |
| Safeguards and Security | 1,679 | 1,617 | 1,626 |
| Total, Oak Ridge Institute for Science and Education | 15,576 | 15,505 | 13,236 |
| | | | |
| Oak Ridge National Laboratory | | | |
| Basic Energy Sciences | 307,468 | 312,456 | 328,986 |
| Advanced Scientific Computing Research | 98,622 | 94,073 | 95,958 |
| Biological and Environmental Research | 64,886 | 67,504 | 60,160 |
| High Energy Physics | 85 | — | — |
| Nuclear Physics | 25,090 | 35,445 | 33,776 |
| Fusion Energy Sciences | 46,028 | 141,214 | 152,084 |
| Science Laboratories Infrastructure | 9,535 | 25,103 | — |
| Safeguards and Security | 7,652 | 8,895 | 8,895 |
| Total, Oak Ridge National Laboratory | 559,366 | 684,690 | 679,859 |
| | | | |
| Oak Ridge National Laboratory Site Office | | | |
| Science Program Direction | — | — | 4,439 |
| | | | |
| Oak Ridge Office | | | |
| Biological and Environmental Research | 50 | — | — |
| Science Laboratories Infrastructure | 5,040 | 5,079 | 5,214 |
| Science Program Direction | 43,274 | 44,948 | 42,305 |
| Safeguards and Security | 18,649 | 18,699 | 19,237 |
| Total, Oak Ridge Office | 67,013 | 68,726 | 66,756 |

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| | (dollars in thousands) | | |
| Office of Scientific and Technical Information | | | |
| Basic Energy Sciences | 100 | 106 | 106 |
| Advanced Scientific Computing Research | 100 | 106 | 106 |
| Biological and Environmental Research | 367 | 373 | 373 |
| High Energy Physics | 100 | 106 | 110 |
| Nuclear Physics | 100 | 106 | — |
| Fusion Energy Sciences | 100 | 106 | 106 |
| Science Laboratories Infrastructure | — | 2,500 | — |
| Science Program Direction | — | 8,916 | 8,916 |
| Workforce Development for Teachers and Scientists | 120 | 105 | 240 |
| Safeguards and Security | 630 | 490 | 490 |
| Total, Office of Scientific and Technical Information | 1,617 | 12,914 | 10,447 |
| | | | |
| Pacific Northwest National Laboratory | | | |
| Basic Energy Sciences | 18,169 | 17,821 | 18,427 |
| Advanced Scientific Computing Research | 5,806 | 6,055 | 2,284 |
| Biological and Environmental Research | 94,710 | 98,961 | 103,907 |
| Nuclear Physics | 150 | — | — |
| Fusion Energy Sciences | 1,053 | 900 | 1,326 |
| Science Laboratories Infrastructure | 24,773 | 52,775 | — |
| Workforce Development for Teachers and Scientists | 715 | 1,221 | 1,412 |
| Safeguards and Security | 11,153 | 11,163 | 11,163 |
| Total, Pacific Northwest National Laboratory | 156,529 | 188,896 | 138,519 |
| | | | |
| Pacific Northwest Site Office | | | |
| Science Program Direction | 5,186 | 5,264 | 6,150 |
| | | | |
| Princeton Plasma Physics Laboratory | | | |
| Advanced Scientific Computing Research | 1,154 | 740 | 688 |
| High Energy Physics | 230 | 230 | 230 |
| Fusion Energy Sciences | 72,436 | 70,318 | 70,219 |
| Workforce Development for Teachers and Scientists | 155 | 315 | 506 |
| Safeguards and Security | 2,368 | 2,075 | 2,104 |
| Total, Princeton Plasma Physics Laboratory | 76,343 | 73,678 | 73,747 |

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| | (dollars in thousands) | | |
| Princeton Site Office | | | |
| Science Program Direction | 1,840 | 1,726 | 2,055 |
| Sandia National Laboratories | | | |
| Basic Energy Sciences | 35,139 | 32,817 | 34,099 |
| Advanced Scientific Computing Research | 6,395 | 6,189 | 6,137 |
| Biological and Environmental Research | 2,060 | 1,870 | 1,300 |
| Nuclear Physics | 300 | 275 | — |
| Fusion Energy Sciences | 2,560 | 2,290 | 2,290 |
| Workforce Development for Teachers and Scientists | 150 | 470 | 786 |
| Congressionally Directed Projects | 7,114 | — | — |
| Total, Sandia National Laboratories | 53,718 | 43,911 | 44,612 |
| Savannah River National Laboratory | | | |
| Basic Energy Sciences | 398 | 300 | 300 |
| Biological and Environmental Research | 754 | 622 | 363 |
| Fusion Energy Sciences | 40 | — | — |
| Workforce Development for Teachers and Scientists | — | — | 100 |
| Total, Savannah River National Laboratory | 1,192 | 922 | 763 |
| SLAC National Accelerator Laboratory | | | |
| Basic Energy Sciences | 183,901 | 212,384 | 177,178 |
| Advanced Scientific Computing Research | 200 | 200 | 200 |
| Biological and Environmental Research | 4,843 | 5,150 | 4,150 |
| High Energy Physics | 103,427 | 87,551 | 91,231 |
| Science Laboratories Infrastructure | — | — | 8,900 |
| Workforce Development for Teachers and Scientists | 160 | 180 | 215 |
| Safeguards and Security | 2,566 | 2,558 | 2,615 |
| Total, SLAC National Accelerator Laboratory | 295,097 | 308,023 | 284,489 |
| Stanford Site Office | | | |
| Science Program Direction | 2,499 | 2,748 | 2,830 |

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Thomas Jefferson National Accelerator Facility | | | |
| Advanced Scientific Computing Research | 100 | 100 | 100 |
| Biological and Environmental Research | 600 | 600 | 600 |
| High Energy Physics | 830 | 1,840 | 1,895 |
| Nuclear Physics | 95,069 | 117,811 | 117,044 |
| Science Laboratories Infrastructure | — | 3,700 | 27,687 |
| Workforce Development for Teachers and Scientists | 292 | 486 | 516 |
| Safeguards and Security | 1,626 | 1,325 | 1,346 |
| Total, Thomas Jefferson National Accelerator Facility | 98,517 | 125,862 | 149,188 |
| | | | |
| Thomas Jefferson Site Office | | | |
| Science Program Direction | 1,995 | 1,828 | 2,225 |
| | | | |
| Washington Headquarters | | | |
| Basic Energy Sciences | 1,538 | 237,568 | 323,916 |
| Advanced Scientific Computing Research | 1,467 | 58,310 | 86,122 |
| Biological and Environmental Research | 858 | 82,737 | 138,417 |
| High Energy Physics | 2,786 | 79,983 | 113,376 |
| Nuclear Physics | 433 | 40,493 | 62,025 |
| Fusion Energy Sciences | 554 | 17,292 | 23,376 |
| Science Laboratories Infrastructure | 1 | 11,385 | 1,385 |
| Science Program Direction | 73,386 | 73,225 | 86,606 |
| Workforce Development for Teachers and Scientists | — | 2,630 | 6,810 |
| Safeguards and Security | 80 | 4,604 | 5,878 |
| Congressionally Directed Projects | — | 24,011 | — |
| Total, Washington Headquarters | 81,103 | 632,238 | 847,911 |
| | | | |
| Waste Isolation Pilot Plant | | | |
| Congressionally Directed Projects | 1,435 | — | — |
| Total, Science | 4,136,071 | 4,772,636 | 4,941,682 |

## Major Changes or Shifts by Site

### Argonne National Laboratory

- **Advanced Scientific Computing Research**: The Leadership Computing Facility will be fully operational at 500 teraflops and will provide open high-performance computing capability with low electrical power consumption to enable scientific advances.
- **Science Laboratories Infrastructure**: The Energy Sciences Building project is initiated to provide safe, efficient, and modern space for research and development. This project will fill that need by providing environmentally stable, specialized, and flexible space that will replace some of the oldest and least effective research space for energy-related sciences.

### Brookhaven National Laboratory

- **Science Laboratories Infrastructure**: The Renovate Science Laboratories—Phase II project is initiated to modernize obsolete and unsuitable laboratory space in Building 510 (Physics) and Building 555 (Chemistry), allowing continue support of research in Basic Energy Sciences, Nuclear Physics, and High Energy Physics.

### Lawrence Berkeley National Laboratory

- **Biological and Environmental Research**: The Joint BioEnergy Institute at Lawrence Berkeley National Laboratory will be fully operational in FY 2009.
- **High Energy Physics**: Funding was provided in the FY 2009 Appropriation for the Berkeley Lab Laser Acceleration Project (BELLA). BELLA will further advance the world-leading laser-driven plasma acceleration program at the L'Oasis laboratory, with a focus on exploring concepts for cascading GeV wakefield accelerating modules, a promising path to higher gradients and energies in compact particle accelerators. L'Oasis has already accelerated high-quality electron beams to energy exceeding 1 GeV in a one-meter long structure. BELLA will initially improve this by a factor of ten, to 10 GeV.

### Los Alamos National Laboratory

- **Nuclear Physics**: Radioisotope related activities at the Isotope Production Facility (IPF) are transferred from the Office of Nuclear Energy to SC in FY 2009.

### Oak Ridge National Laboratory

- **Advanced Scientific Computing Research**: The Leadership Computing Facility will be fully operational at one petaflop and will provide open high-performance computing capability to enable scientific advances.
- **Biological and Environmental Research**: The BioEnergy Science Center at the Oak Ridge National Laboratory will be fully operational in FY 2009.
- **Fusion Energy Sciences**: Funding for the U.S. Contributions to ITER MIE Project is increased in FY 2010 by $11.0M.

### Oak Ridge National Site Office

- **Science Program Direction**: Federal oversight of contract performance at the Oak Ridge National Laboratory is realigned to the Oak Ridge National Laboratory Site Office from the Oak Ridge Office.

### Oak Ridge Office

- **Science Program Direction**: Federal oversight of contract performance at the Oak Ridge National Laboratory is realigned from the Oak Ridge Office to the Oak Ridge National Laboratory Site Office.

### Princeton Plasma Physics Laboratory

- **Fusion Energy Sciences**: The FY 2009 Congressional Request included funding for NCSX Research ($692,000) and the NCSX MIE project ($19,560,000). Due to cancellation of the project in May 2008, closeout costs were provided for in FY 2008, and the FY 2009 funding has been redirected to provide increases in facilities operations and upgrades ($16,823,000) and experimental plasma research on smaller-scale stellarators ($3,429,000). One of the upgrades that was started in FY 2009 and will continue in FY 2010 is to enhance the capability of the National Spherical Torus Experiment at PPPL.

### SLAC National Accelerator Laboratory

- **Basic Energy Sciences**: FY 2010 marks the completion of construction for the Linac Coherent Light Source (LCLS) project. The LCLS will begin its first full year of operations as a DOE user facility in FY 2011.
- **High Energy Physics**: In FY 2010, SLAC plans to complete construction of the Facility for Accelerator Science and Experimental Test Beams (FACET) and begin preparations for the first round of experiments in which electrons are accelerated by plasma wakefields. Much of the work on advanced accelerator concepts at SLAC is done in collaboration with universities funded by the Accelerator Science research activity. The ultimate goal of this effort will be demonstration of efficient accelerating structures with gradients well above 100 MeV/m that could be incorporated into future accelerators.
- **Science Laboratories Infrastructure**: The Research Support Building and Infrastructure Modernization project is initiated to replace substandard modular buildings and trailers that are well beyond their intended useful life with a new Research Support Building to allow collocation of the Accelerator Science and Technology program at the laboratory. The project will also modernize three existing buildings onsite.

## Site Description

### Ames Laboratory

The Ames Laboratory is a program dedicated laboratory (Basic Energy Sciences). The laboratory is located on the campus of the Iowa State University, in Ames, Iowa, and consists of 12 buildings (327,664 gross square feet of space) with the average age of the buildings being 41 years. DOE does not own the land. Ames conducts fundamental research in the physical, chemical, and mathematical sciences associated with energy generation and storage; and is a national center for the synthesis, analysis, and engineering of rare-earth metals and their compounds.

- **Basic Energy Sciences**: Ames supports experimental and theoretical research on rare earth elements in novel mechanical, magnetic, and superconducting materials. Ames scientists are experts on magnets, superconductors, and quasicrystals that incorporate rare earth elements. Ames also supports theoretical studies for the prediction of molecular energetics and chemical reaction rates and provides leadership in analytical and separations chemistry. Ames is home to the Materials Preparation Center, which is dedicated to the preparation, purification, and characterization of rare-earth, alkaline-earth, and refractory metal and oxide materials.
- **Advanced Scientific Computing Research**: Ames conducts research in computer science and participates on Scientific Discovery through Advanced Computing (SciDAC) science application teams.
- **Safeguards and Security**: This program provides planning, policy, implementation, and oversight in the areas of security systems, security officers, personnel security, program management, material control and accountability, and cyber security.

### Ames Site Office

The Ames Site Office provides the single federal presence with responsibility for contract performance at the Ames Laboratory. This site office provides an on-site SC presence with authority encompassing contract management, program and project implementation, federal stewardship, and internal operations.

### Argonne National Laboratory

The Argonne National Laboratory (ANL) in Argonne, Illinois, is a multiprogram laboratory located on 1,500 acres in suburban Chicago. The laboratory consists of 100 buildings (4.6 million gross square feet of space) with an average building age of 37 years.

- **Basic Energy Sciences**: ANL is home to research activities in broad areas of materials and chemical sciences. It is also the site of three user facilities—the Advanced Photon Source (APS), the Center for Nanoscale Materials (CNM), and the Electron Microscopy Center (EMC) for Materials Research.
  - The **Advanced Photon Source** 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 **Electron Microscopy Center for Materials Research** 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. The unique combination of two ion accelerators and an electron microscope permits direct, real-time, *in-situ* observation of the effects of ion bombardment of materials. 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.

- The **Center for Nanoscale Materials** provides capabilities for developing new methods for self assembly of nanostructures, exploring the nanoscale physics and chemistry of nontraditional electronic materials, and creating new probes for exploring nanoscale phenomena. The CNM is organized around six scientific themes: nanomagnetism, bio-inorganic hybrids, nanocarbon, complex oxides, nanophotonics, and theory and simulation.

- **Advanced Scientific Computing Research**: ANL conducts basic research in mathematics and computer science, as well as research in advanced computing software tools. ANL also participates in scientific application partnerships and contributes to a number of the SciDAC science application teams. Further, it participates in both SciDAC Centers for Enabling Technologies and SciDAC Institutes that focus on specific software challenges confronting users of petascale computers. The ANL Leadership Computing Facility provides the computational science community with a world-leading computing capability dedicated to breakthrough science and engineering. The Leadership Computing Facility provides resources, including a 500 teraflop IBM Blue Gene/P system, which make computationally intensive projects of the largest scales possible.

- **Biological and Environmental Research**: ANL conducts research on the molecular control of genes and gene pathways in microbes in addition to biological and geochemical research that supports environmental remediation. ANL operates beamlines for protein crystallography at the APS and also supports a growing community of users in environmental sciences.

  In support of climate change research, ANL has oversight responsibility for coordinating the overall infrastructure operations of all three stationary Atmospheric Radiation Measure (ARM) Climate Research Facility (ACRF) sites to ensure consistency, data quality, and site security and safety. This includes infrastructure coordination of communications, data transfer, and instrument calibration. ANL also provides the site manager for the Southern Great Plains site who is responsible for coordinating the day-to-day operations and manages the deployment and operation of the ACRF second mobile facility. ANL conducts research on aerosol processes and properties, and develops and applies software to enable efficient long-term climate simulations on distributed-memory multiprocessor computing platforms. In conjunction with Oak Ridge National Laboratory, Pacific Northwest National Laboratory, and six universities, ANL is a participating laboratory in the Carbon Sequestration in Terrestrial Ecosystems (CSiTE) consortium, focusing on research to understand the processes controlling the rate of soil carbon accretion.

- **High Energy Physics**: ANL has unique capabilities in the areas of engineering, detector technology, and advanced accelerator and computing techniques. ANL continues to participate in the Tevatron and neutrino research programs at Fermi National Accelerator Laboratory (Fermilab) and analysis of data from these experimental programs will continue for several years. Other major ANL activities include work on the ATLAS (A Large Toroidal LHC Apparatus) experiment at the Large Hadron Collider, advanced accelerator R&D using the Argonne Wakefield Accelerator, and an important role in collaboration with Fermilab in the development of superconducting radio frequency technology for future accelerators and development of new detector technologies.

  - The **Argonne Wakefield Accelerator** is an R&D testbed that focuses on the physics and technology of high-gradient, dielectric-loaded structures for accelerating electrons. Two approaches are being pursued: a collinear, electron-beam driven dielectric-loaded wakefield accelerator; and a two-beam accelerator. The goal is to identify and develop techniques which may lead to more efficient, compact, and inexpensive particle accelerators for future HEP applications. Research activities at this facility include: the development of materials/coatings for high gradient research; dielectric-loaded and photonic band gap accelerating structures; lefthanded meta-materials, high-power/high-brightness electron beams, and advanced beam diagnostics.

- **Nuclear Physics**: ANL operates and runs the R&D program for the Argonne Tandem Linac Accelerator System (ATLAS) national user facility, the world's premiere stable beam facility. Other activities include an on-site program of research using laser techniques (Atom Trap Trace Analysis); research programs at the Thomas Jefferson National Accelerator Facility (TJNAF), Fermilab, Relativistic Heavy Ion Collider (RHIC), and Deutsches Elektronen-Synchrotron (DESY) in Germany investigating the structure of the nucleon; R&D for the Facility for Rare Isotope Beams (FRIB); theoretical calculations and investigations in subjects supporting the experimental research programs in Medium Energy and Low Energy physics; and data compilation and evaluation activities as part of the National Nuclear Data Program.
  - The **Argonne Tandem Linac Accelerator System** national user facility provides variable energy and precision beams of stable ions from protons through uranium at energies near the Coulomb barrier (up to 10 MeV per nucleon) using a superconducting linear accelerator. Most work is performed with stable heavy-ion beams; however, about 10 to 20 percent of the beams are rare isotope beams. The ATLAS facility features a wide array of experimental instrumentation, including a world-leading ion-trap apparatus, the Advanced Penning Trap. The Gammasphere detector, coupled with the Fragment Mass Analyzer, is a unique world facility for measurement of nuclei at the limits of angular momentum (high-spin states). ATLAS staff are world leaders in superconducting linear accelerator technology, with particular application in rare isotope beam facilities. The combination of versatile beams and powerful instruments enables about 400 users annually at ATLAS to conduct research in a broad program in nuclear structure and dynamics, nuclear astrophysics, and fundamental interaction studies. The capabilities of ATLAS are being augmented by the fabrication of the CAlifornium Rare Ion Beam Upgrade (CARIBU) as a source to provide new capabilities in neutron-rich radioactive beams. A new instrument, the Helical Orbital Spectrometer (HELIOS), employs a new concept to study reactions with radioactive beams from CARIBU.
- **Fusion Energy Sciences**: ANL contributes a small effort in basic plasma science.
- **Science Laboratories Infrastructure**: SLI enables DOE research missions at ANL by funding line item construction to maintain the general purpose infrastructure and the cleanup and removal of excess facilities.
- **Safeguards and Security**: This program provides protection of special nuclear materials, classified matter, government property, and other vital assets from unauthorized access, theft, diversion, sabotage, espionage, and other hostile acts that may cause risks to national security, the health and safety of DOE and contractor employees, the public, or the environment.

### Argonne Site Office

The Argonne Site Office provides the single federal presence with responsibility for contract performance at ANL. This site office provides an on-site SC presence with authority encompassing contract management, program and project implementation, federal stewardship, and internal operations.

### Berkeley Site Office

The Berkeley Site Office provides the single federal presence with responsibility for contract performance at the Lawrence Berkeley National Laboratory. This site office provides an on-site SC presence with authority encompassing contract management, program and project implementation, federal stewardship, and internal operations.

**Brookhaven National Laboratory**

The Brookhaven National Laboratory (BNL) is a multiprogram laboratory located on 5,300 acres in Upton, New York. The laboratory consists of 334 SC buildings (4.0 million gross square feet of space) with an average building age of 38 years. BNL creates and operates major facilities available to university, industrial, and government personnel for basic and applied research in the physical, biomedical, and environmental sciences, and in selected energy technologies.

- **Basic Energy Sciences**: BNL conducts research efforts in materials and chemical sciences as well as efforts in geosciences and biosciences. It is also the site of two BES supported user facilities—the National Synchrotron Light Source (NSLS) and the Center for Functional Nanomaterials (CFN).
  - The **National Synchrotron Light Source** 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 understand the atomic and electronic structure as well as the magnetic properties of a wide array of materials.
  - The **Center for Functional Nanomaterials** focuses on understanding the chemical and physical response of nanomaterials to make functional materials such as sensors, activators, and energy-conversion devices. It also provides clean rooms, general laboratories, and wet and dry laboratories for sample preparation, fabrication, and analysis. Equipment includes that needed for laboratory and fabrication facilities for e-beam lithography, transmission electron microscopy, scanning probes and surface characterization, material synthesis and fabrication, and spectroscopy.
- **Advanced Scientific Computing Research**: BNL conducts basic research in applied mathematics and participates on SciDAC science application teams. It also participates in SciDAC Centers for Enabling Technologies that focus on specific software challenges confronting users of petascale computers.
- **Biological and Environmental Research**: BNL operates beam lines for protein crystallography at the NSLS for use by the national biological research community, research in biological structure determination, and research into new instrumentation for detecting x-rays and neutrons. Research is also conducted in support of metabolic synthesis and conversion and on the molecular mechanisms of cell responses to low doses of radiation. BNL conducts molecular radiochemistry and imaging and instrumentation research, developing advanced technologies for biological imaging. BNL scientists support the subsurface biogeochemical research program in the area of subsurface contaminant fate and transport.
  - Climate change research includes the operation of the ACRF External Data resource that provides atmospheric system research investigators with data from non-ACRF sources, including satellite and ground-based systems. BNL scientists form an important part of the atmospheric system research science team, including providing special expertise in analyzing atmospheric field campaign data and aerosol research.

- BNL scientists play a leadership role in the operation of the Free-Air Carbon Dioxide Enrichment (FACE) experiment at the Duke Forest which seeks to understand how plants respond to elevated carbon dioxide concentrations in the atmosphere.

▪ **High Energy Physics**: BNL has unique resources in the engineering and technology for future accelerators and detectors, advanced computational resources, and the Accelerator Test Facility. BNL serves as the host laboratory for the U.S. ATLAS collaboration, which participates in the research of the ATLAS detector at the Large Hadron Collider. BNL manages the program of maintenance and operations for the ATLAS detector, operates the primary U.S. analysis facility for ATLAS data, and is developing an analysis support center for U.S. based users. The group also contributes to the leadership and management of the U.S. International Linear Collider R&D effort.

  BNL researchers have a leadership role in the Reactor Neutrino experiment in Daya Bay, China, BNL physicists are also involved in other neutrino physics efforts including research at the Neutrinos at the Main Injector (NuMI) facility with the Main Injector Neutrino OScillation (MINOS) experiment at Fermilab and R&D and planning for possible future accelerator-based neutrino experiments.

  - The BNL **Accelerator Test Facility** is a user facility that supports a broad range of advanced accelerator R&D. The core capabilities include a high-brightness photoinjector electron gun, a 70 MeV linac, high power lasers synchronized to the electron beam to a picosecond level, four beam lines, and a sophisticated computer control system. Participating researchers come from universities, national laboratories, and industries. Experiments carried out in this facility are proposal-driven and are typically in the areas involving interactions of high power electromagnetic radiation and high brightness electron beams, including laser acceleration of electrons and free-electron lasers. Other topics include the development of electron beams with extremely high brightness, photo-injectors, electron beam and radiation diagnostics, and computer controls.

▪ **Nuclear Physics**: Research activities include: use of relativistic heavy ion beams and polarized protons in the Relativistic Heavy Ion Collider (RHIC) to investigate hot, dense nuclear matter and to understand the internal “spin” structure of the proton, respectively—parts of which are coordinated with the RIKEN BNL Research Center funded by Japan; development of future detectors for RHIC; R&D of beam-cooling accelerator technology aimed at increasing the RHIC beam luminosity; conducting R&D directed towards research with neutrinos; a theory program emphasizing RHIC heavy ion and “spin” physics; and data compilation and evaluation at the National Nuclear Data Center (NNDC) that is the central U.S. site for these national and international efforts.

  - The **Relativistic Heavy Ion Collider** facility uses the Tandem Van de Graaff, Booster Synchrotron, and Alternating Gradient Synchrotron (AGS) accelerators in combination to inject beams into two rings of superconducting magnets of almost 4 kilometers circumference with 6 intersection regions where the beams can collide. RHIC can accelerate and collide a variety of heavy ions, including gold beams, up to an energy of 100 GeV per nucleon. RHIC is being used to search for and characterize hot, dense nuclear matter such as the predicted “quark-gluon plasma,” a form of nuclear matter thought to have existed microseconds after the “Big Bang.” It can also collide polarized protons with beams of energy up to 250 GeV per nucleon—a unique capability. Two detectors are supported to provide complementary measurements, with some overlap in order to cross-calibrate the measurements: the Solenoidal Tracker at RHIC (STAR) and the Pioneering High-Energy Nuclear Interacting Experiment (PHENIX).

- The **Alternating Gradient Synchrotron** provides high intensity pulsed proton beams up to 33 GeV on fixed targets and secondary beams of kaons, muons, pions, and anti-protons. The AGS is the injector of (polarized) proton and heavy-ion beams into RHIC, and its operations are supported by the NP Heavy Ion subprogram as part of the RHIC facility. The AGS is also utilized for radiation damage studies of electronic systems for NASA-supported work and work for other agencies.
- The **Booster Synchrotron**, part of the RHIC injector, provides heavy-ion beams to a dedicated beam line (NASA Space Radiation Laboratory) for biological and electronic systems radiation studies funded by NASA. The incremental costs for these studies are provided by NASA.
- The **Tandem Van de Graaff** accelerators which serve as injectors for the Booster Synchrotron are being replaced by a modern, compact Electron Beam Ion Source (EBIS) and linac system which promises greater efficiency, greater reliability, and lower maintenance costs as well as the potential for future upgrades. The EBIS is a joint DOE/NASA project and will be completed in FY 2010.
- The **National Nuclear Data Center** is the central U.S. site for national and international nuclear data and compilation efforts. The U.S. Nuclear Data program is the United States' repository for information generated in low- and intermediate-energy nuclear physics research worldwide. This information consists of both bibliographic and numeric data. The NNDC is a resource for a very broad user community in all aspects of nuclear technology, with relevance to homeland security and advanced fuel cycles for nuclear reactors. Nuclear Data program-funded scientists at U.S. national laboratories and universities contribute to the activities and responsibilities of the NNDC.
- The **Brookhaven Linear Isotope Producer (BLIP)** at BNL uses a linear accelerator that injects 200 million-electron-volt (MeV) protons into the 33 giga-electron-volt (GeV) Alternating Gradient Synchrotron. Isotopes produced, such as strontium-82, germanium-68, copper-67, and others, are used in medical diagnostic and therapeutic applications and other scientific research.

▪ **Science Laboratories Infrastructure**: SLI enables DOE research missions at BNL by funding line item construction to maintain the general purpose infrastructure, and the cleanup and removal of excess facilities.

▪ **Safeguards and Security**: S&S activities at BNL are focused on protective forces, cyber security, personnel security, security systems, information security, program management, and material control and accountability.

### Brookhaven Site Office

The Brookhaven Site Office provides the single federal presence with responsibility for contract performance at BNL. This site office provides an on-site SC presence with authority encompassing contract management, program and project implementation, federal stewardship, and internal operations.

### Chicago Office

The Chicago (CH) Office supports the Department's programmatic missions in science and technology, national nuclear security, energy resources, and environmental quality by providing expertise and assistance in such areas as contract management, procurement, project management, engineering, facilities and infrastructure, property management, construction, human resources, financial management, general and patent law, environmental protection, quality assurance, integrated safety management, integrated safeguards and security management, nuclear material control and accountability, and emergency management. CH directly supports site offices responsible for program management oversight of six major management and operating laboratories—Ames Laboratory, Argonne National Laboratory, Lawrence Berkeley National Laboratory, Brookhaven National Laboratory, Fermi National Accelerator Laboratory, and Princeton Plasma Physics Laboratory—and one government-owned and government-operated Federal laboratory, New Brunswick Laboratory. Additionally, the administrative, business, and technical expertise of CH is shared SC-wide through the Integrated Support Center concept. CH serves as SC's grant center, administering grants to 272 colleges/universities in all 50 states, Washington, D.C., and Puerto Rico, as determined by the DOE-SC program offices as well as non-SC offices.

**Basic Energy Sciences**: BES funds research at 173 academic institutions located in 48 states.

- **Advanced Scientific Computing Research**: ASCR funds research at over 70 academic institutions supporting over 130 principal investigators.
- **Biological and Environmental Research**: BER funds research at over 200 institutions, including colleges, universities, private industry, and other federal and private research institutions located in 45 states, Washington, DC, and Puerto Rico.
- **High Energy Physics**: HEP supports about 300 research groups at more than 100 colleges and universities located in 36 states, Washington, D.C., and Puerto Rico.
- **Nuclear Physics**: NP funds 185 research grants at 87 colleges and universities located in 34 states and the District of Columbia.
- **Fusion Energy Sciences**: FES funds research grants and cooperative agreements at more than 50 colleges and universities located in approximately 30 states.
- **Safeguards and Security**: S&S at CH provides for contractor protective forces for the Fermi National Accelerator Laboratory and Homeland Security Presidential Directive-12 implementation cost and maintenance.

**Fermi National Accelerator Laboratory**

Fermi National Accelerator Laboratory is a program-dedicated laboratory (High Energy Physics) located on a 6,800-acre site in Batavia, Illinois. The laboratory consists of 355 buildings (2.2 million gross square feet of space) with an average building age of 42 years. Fermilab is the largest U.S. laboratory for research in high-energy physics and is second in size only to CERN, the European Laboratory for Particle Physics. About 2,000 scientific users, scientists from universities and laboratories throughout the U.S. and around the world, use Fermilab for their research. Fermilab's mission is that of the high-energy physics program: to understand matter at its deepest level, to identify its fundamental building blocks, and to understand how the laws of nature determine their interactions.

- **Advanced Scientific Computing Research**: Fermilab participates in some SciDAC science application teams relevant to physics research, accelerator modeling, and distributed data. Fermilab also participates in SciDAC Centers for Enabling Technologies that focus on specific software challenges confronting users of petascale computers.
- **High Energy Physics**: Fermilab is the principal experimental facility for HEP. Fermilab operates the **Tevatron** accelerator and colliding beam facility, which consists of a four-mile ring of superconducting magnets and two large multi-purpose detectors and is capable of accelerating protons and antiprotons to an energy of one trillion electron volts (1 TeV). The Tevatron Collider is the highest energy proton accelerator in the world, and will remain so until the Large Hadron

Collider (LHC) begins operation at CERN in 2009. The laboratory supports two Tevatron experiments, CDF and DZero, together home to about 1,500 physicists from Fermilab and other national labs, U.S. universities, and foreign universities and research institutes.

- The Tevatron complex includes the **Neutrinos at the Main Injector (NuMI)** beamline, the world's highest intensity neutrino beam facility, which started operation in 2005. NuMI provides a controlled beam of neutrinos to the Main Injector Neutrino OScillation (MINOS) experiment located in the Soudan Mine in Minnesota. New experiments (Minerva and NOvA) that will make further use of the NuMI beam began fabrication in FY 2008.
- Fermilab is host laboratory for the U.S. Compact Muon Solenoid (CMS) collaboration, which conducts research using the CMS detector at the LHC. Fermilab manages the program of maintenance and operations for the CMS detector and operates the primary U.S. data analysis center for CMS. Fermilab is also the host laboratory for the LHC Accelerator Research Program which manages U.S. accelerator physicists' efforts on the commissioning, operations, and upgrades of the LHC.
- Fermilab is a leading national laboratory for research and development of future particle accelerator technologies. For example, the large scale infrastructure needed for the fabrication, processing, and testing of superconducting radio frequency (RF) cavities and cryomodules is being built at Fermilab. This includes horizontal and vertical test stands for cavity testing, high quality clean rooms and well-equipped rigging areas for assembly of cryomodules. Fermilab is the lead U.S. laboratory coordinating the national R&D program in this area.
- Fermilab also has an active program in particle astrophysics and cosmology. Fermilab is leading the development and fabrication of a camera to be used in the Dark Energy Survey, has significant participation in research on the direct detection of dark matter and ultra high energy cosmic rays, and is doing R&D towards next generation dark energy experiments.
- Fermilab also has a significant program for R&D on advanced detector components for a variety of physics applications. The laboratory maintains and operates a fixed target beam for testing of detector elements. The facility hosts both university and international groups.

▪ **Safeguards and Security**: The S&S program maintains security officers and operations to protect personnel and the facility, cyber security, program management, security systems, and material control and accountability programs to accurately account for the facility's special nuclear materials.

### Fermi Site Office

The Fermi Site Office provides the single federal presence with responsibility for contract performance at Fermilab. This site office provides an on-site SC presence with authority encompassing contract management, program and project implementation, federal stewardship, and internal operations.

### Idaho National Laboratory

Idaho National Laboratory (INL) is a multiprogram laboratory located on 572,000 acres in Idaho Falls, Idaho. Within the laboratory complex are nine major applied engineering, interim storage, and research and development facilities.

▪ **Basic Energy Sciences**: INL supports studies to understand and improve the life expectancy of material systems used in engineering.

- **Biological and Environmental Research**: INL is conducting research in subsurface biogeochemical research related to clean up of the nuclear weapons complex with an emphasis on understanding coupled processes affecting contaminant transport.
- **Fusion Energy Sciences**: Research at INL focuses on the safety aspects of magnetic fusion concepts for existing and future machines, such as a burning plasma experiment, and further developing the domestic fusion safety database using existing collaborative arrangements to conduct work on international facilities. In addition, INL has expanded their research and facilities capabilities to include tritium science activities at the Safety and Tritium Applied Research (STAR) national user facility—a small tritium laboratory where the fusion program can conduct tritium material science, chemistry, and safety experiments. INL also coordinates safety codes and standards within the ITER program.
- **Nuclear Physics:** The Advanced Test Reactor is supported for the production of select isotopes for the Isotope Program, such as Gd-153, an important isotope for applications such as positron emission tomography (PET) imaging.

### Lawrence Berkeley National Laboratory

The Lawrence Berkeley National Laboratory (LBNL) is a multiprogram laboratory located in Berkeley, California, on a 200-acre site adjacent to the Berkeley campus of the University of California. The laboratory consists of 106 buildings (1.7 million gross square feet of space) with an average building age of 39 years. LBNL is dedicated to performing leading-edge research in the biological, physical, materials, chemical, energy, and computer sciences. The land is leased from the University of California.

- **Basic Energy Sciences**: LBNL is home to major research efforts in materials and chemical sciences as well as to efforts in geosciences, engineering, and biosciences. It is also the site of three Basic Energy Sciences supported user facilities—the Advanced Light Source (ALS), the National Center for Electon Microscopy (NCEM), and the Molecular Foundry.
  - The **Advanced Light Source** provides vacuum-ultraviolet light and 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. The ALS User Support Building (USB) will provide high-quality user support space in sufficient quantity to accommodate the very rapid growth in the number of ALS users and to accommodate projected future expansion of beamlines, instruments and accelerator upgrades. The USB will contain staging areas for ALS experiments, space for a long beamline that will extend from the floor of the ALS into the USB, and temporary office space for visiting users.
  - The **National Center for Electron Microscopy** 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., the Transmission Electron Aberration Corrected Microscope.

- The **Molecular Foundry** provides users with instruments, techniques, and collaborators to enhance the study of the synthesis, characterization, and theory of nanoscale materials. Its focus is on the multidisciplinary development and understanding of both “soft” (biological and polymer) and “hard” (inorganic and microfabricated) nanostructured building blocks and the integration of these building blocks into complex functional assemblies. Scientific themes include inorganic nanostructures; nanofabrication; organic, polymer, and biopolymer nanostructures; biological nanostructures; imaging and manipulation of nanostructures; and theory of nanostructures. The facility offers expertise in a variety of techniques for the study of nanostructures, including electronic structure and excited-state methods, *ab initio* and classical molecular dynamics, quantum transport, and classical and quantum Monte Carlo approaches.

▪ **Advanced Scientific Computing Research**: LBNL conducts basic research in mathematics and computer science, as well as research in advanced computing software tools. LBNL also participates in several SciDAC science application teams, and both SciDAC Centers for Enabling Technologies and SciDAC Institutes that focus on specific software challenges confronting users of petascale computers. LBNL manages the ESnet. ESnet is one of the worlds most effective and progressive science-related computer networks that provides worldwide access and communications to Department of Energy facilities. LBNL is also the site of the National Energy Research Scientific Computing Center (NERSC), which provides a range of high-performance, state-of-the-art computing resources that are a critical element in the success of many SC research programs.

▪ **Biological and Environmental Research**: LBNL is the lead national laboratory that manages the **Joint Genome Institute (JGI)**, the principal goal of which is high-throughput DNA sequencing techniques. The laboratory also conducts research on the molecular mechanisms of cell responses to low doses of radiation and on microbial systems biology research as part of Genomic Science. LBNL operates beamlines for determination of protein structure at the ALS for use by the national and international biological research community. The ALS also supports and is used by a growing environmental science community.

  LBNL supports subsurface biogeochemical research and provides geophysical, biophysical, and biochemical research capabilities for field sites and is participating in the NSF/DOE Environmental Molecular Sciences Institute at Pennsylvania State University.

  LBNL conducts research on carbon cycling and carbon sequestration on terrestrial ecosystems to understand the processes controlling the exchange of $CO_2$ between terrestrial ecosystems and the atmosphere. It also conducts research on biological and ecological responses to climatic and atmospheric changes.

  It also develops scalable implementation technologies that allow widely used climate models to run effectively and efficiently on massively parallel processing supercomputers.

  - The **Joint BioEnergy Institute (JBEI)** at LBNL, one of three Genomic Science Bioenergy Research Centers, is focused on model plant systems (*Arabidopsis* and rice) for which the laboratory capabilities are well developed. Early results on their more tractable genomics will be shifted to potential bioenergy feedstock plants. The JBEI is experimenting with *E. Coli* and yeast, two workhorse microbes for conversion, as well as the use of ionic liquids for deconstruction of biomass material. JBEI is also investigating biological production of alternatives to ethanol that would be better substitutes for gasoline and diesel.

▪ **High Energy Physics**: LBNL has unique capabilities in the areas of superconducting magnet R&D, engineering and detector technology, laser driven particle acceleration, the design of advanced electronic devices, computational resources, and the design of modern, complex software codes for HEP experiments. LBNL participates in the research of the ATLAS detector at the Large Hadron Collider, and has a leading role in providing the software and computing infrastructure for ATLAS. LBNL physicists are also involved in neutrino physics research using reactor-produced neutrinos, and provide management expertise to the Reactor Neutrino experiment at Daya Bay, China.

LBNL also has an active program in particle astrophysics and cosmology, providing leadership in the development of innovative detector technologies and in the application of high energy physics analysis methods to astronomical observations. LBNL physicists lead ongoing studies of dark energy using supernovae and baryon acoustic oscillations; this science team continues R&D for a space-based dark energy mission. LBNL operates the Microsystems Lab where new detector technologies have been developed for collider physics research and new devices to study dark energy and the cosmic microwave background. LBNL is also host to the annually updated Particle Data Group, which coordinates compilation and synthesis of high-energy physics experimental data into compendia which summarize the status of all major subfields of HEP.

- **Nuclear Physics**: LBNL supports a variety of activities focused primarily in the low energy and heavy ion NP subprograms. These include fabrication of a next-generation gamma-ray detector system, GRETINA; research with the STAR detector located at BNL's RHIC facility; development of future detector systems for RHIC; operation of the Parallel Distributed Systems Facility aimed at heavy ion and low energy physics computation; fabrication of a detector upgrade for the ALICE detector heavy ion program at the Large Hadron Collider (LHC) in Europe; research at the KamLAND detector in Japan that is performing neutrino studies; development and fabrication of next generation neutrino detectors, including leading the effort on U.S. participation in the Cryogenic Underground Observatory for Rare events (CUORE) experiment in Italy; a theory program with an emphasis on relativistic heavy ion physics; data compilation and evaluation activities supporting the National Nuclear Data Center at BNL; and R&D with the development of electron-cyclotron resonance (ECR) ion sources for the Facility for Rare Isotope Beams (FRIB). The 88-Inch Cyclotron at LBNL is a facility for testing electronic circuit components for radiation "hardness" to cosmic rays, supported by the National Reconnaissance Office and the U.S. Air Force, and for a small in-house research program supported by NP.

- **Fusion Energy Sciences**: LBNL has been conducting research in developing ion beams for applications to high energy density laboratory plasmas (HEDLP) in the near term (4 to 10 years) and inertial fusion energy in the long term. Currently the laboratory has two major experimental systems for doing this research: the Neutralized Drift Compression Experiment and the High Current Experiment. Both experiments are directed at answering the question of how ion beams can be produced with the intensity required for research in HEDLP and inertial fusion energy sciences. LBNL conducts this research together with the Lawrence Livermore National Laboratory and Princeton Plasma Physics Laboratory through the Heavy Ion Fusion Science Virtual National Laboratory.

- **Science Laboratories Infrastructure**: SLI enables DOE research missions at LBNL by funding line item construction to maintain the general purpose infrastructure and the cleanup and removal of excess facilities.

- **Safeguards and Security**: S&S at LBNL provides physical protection of personnel and laboratory facilities through utilization of security officers, security systems, cyber security, program management, personnel security, and material control and accountability for special nuclear material.

**Lawrence Livermore National Laboratory**

Lawrence Livermore National Laboratory (LLNL) is a multiprogram laboratory located on 821 acres in Livermore, California. This laboratory was built in Livermore as a weapons laboratory 42 miles from the campus of the University of California at Berkeley to take advantage of the expertise of the university in the physical sciences.

- **Basic Energy Sciences**: LLNL supports research in materials sciences and in geosciences research on the sources of electromagnetic responses in crustal rocks, seismology theory and modeling, the mechanisms and kinetics of low-temperature geochemical processes and the relationships among reactive fluid flow, geochemical transport, and fracture permeability.
- **Advanced Scientific Computing Research**: LLNL participates in base applied mathematics and computer science research. LLNL also participates in several SciDAC science application teams and both SciDAC Centers for Enabling Technologies and SciDAC Institutes that focus on specific software challenges confronting users of petascale computers.
- **Biological and Environmental Research**: LLNL is one of the major national laboratory partners that support the Joint Genome Institute (JGI), the principal goal of which is high-throughput DNA sequencing. LLNL is also developing new biocompatible materials and microelectronics for the artificial retina project and conducts research on the molecular mechanisms of cell responses to low doses of radiation.

  Through the program for Climate Model Diagnosis and Intercomparison, LLNL provides the international leadership to develop and apply diagnostic tools to evaluate and improve the performance of climate models. Virtually every climate modeling center in the world participates in this unique program. It also conducts research to improve understanding of the climate system, particularly the climate effect of clouds and aerosol properties and processes and climate change feedbacks on carbon cycling.
- **High Energy Physics**: HEP supports experimental physics research and technology R&D at LLNL, using unique capabilities of the laboratory primarily in the areas of engineering and detector technology and advanced accelerator R&D.
- **Nuclear Physics**: The LLNL program supports research in relativistic heavy ion physics as part of the PHENIX collaboration at RHIC and the ALICE experiment at the LHC, in nuclear data and compilation activities, in R&D for neutrino-less double beta decay experiments, and on theoretical nuclear structure studies.
- **Fusion Energy Sciences**: LLNL works with LBNL and PPPL through the Heavy-Ion Fusion Virtual National Laboratory in advancing the physics of heavy ion beams as a driver for inertial fusion energy in the long term and high energy density laboratory plasmas in the near term. It also conducts research on fast ignition concepts for applications in research on high energy density physics and inertial fusion energy. The LLNL program also includes collaborations with General Atomics on the DIII-D tokamak and benchmarking of fusion physics computer models with experiments such as DIII-D. LLNL carries out research in the simulation of turbulence and its effect on transport of heat and particles in magnetically confined plasmas. In addition, LLNL carries out research in support of plasma chamber and plasma-material interactions.

**Los Alamos National Laboratory**

Los Alamos National Laboratory (LANL) is a multiprogram laboratory located on 30,413 acres in Los Alamos, New Mexico.

- **Basic Energy Sciences**: LANL is home to efforts in materials sciences, chemical sciences, geosciences, and engineering. LANL research includes work on strongly correlated electronic materials, high-magnetic fields, microstructures, deformation, alloys, bulk ferromagnetic glasses, mechanical properties, metastable phases and microstructures, alkaline fuel cells, and bioinspired molecular assemblies for energy conversion. Research is also supported to understand the electronic structure and reactivity of actinides the chemistry of plutonium and other light actinides in both near-neutral pH conditions and under strongly alkaline conditions relevant to radioactive wastes, and the physical electrochemistry fundamental to energy storage systems. In the areas of geosciences, experimental and theoretical research is supported on rock physics, seismic imaging, the physics of the earth's magnetic field, fundamental geochemical studies of isotopic equilibrium/disequilibrium, and mineral-fluid-microbial interactions.

  LANL is also the site of two BES supported user facilities: the Manuel Lujan Jr. Neutron Scattering Center (Lujan Center) and the Center for Integrated Nanotechnologies (CINT).

  - The **Manuel Lujan Jr. Neutron Scattering Center** 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 extensive experience in handling actinide samples. The Lujan Center is part of the Los Alamos Neutron Science Center (LANSCE), which is comprised of a high-power 800-MeV proton linear accelerator, a proton storage ring, production targets to the Lujan Center and the Weapons Neutron Research facility, and a variety of associated experiment areas and spectrometers for national security research and civilian research.
  - The **Center for Integrated Nanotechnologies** is devoted to establishing the scientific principles that govern the design, performance, and integration of nanoscale materials. Through its core facility in Albuquerque, New Mexico, and its gateways to both Sandia National Laboratories and Los Alamos National Laboratory, CINT provides access to tools and expertise to explore the continuum from scientific discovery to the integration of nanostructures into the microworld and the macroworld. CINT supports five scientific thrusts that serve as synergistic building blocks for integration research: nano-bio-micro interfaces, nanophotonics and nanoelectronics, complex functional nanomaterials, nanomechanics, and theory and simulation.

- **Advanced Scientific Computing Research**: LANL conducts basic research in mathematics and computer science and in advanced computing software tools. LANL also participates in several SciDAC science application teams and both SciDAC Centers for Enabling Technologies and SciDAC Institutes, which focus on specific software challenges confronting users of petascale computers.
- **Biological and Environmental Research**: LANL is one of the major national laboratory partners that support the JGI, the principal goal of which is high-throughput DNA sequencing and studies on the biological functions associated with newly sequenced human DNA. One of LANL's roles in the JGI involves the production of high quality "finished" DNA sequence. It also conducts research on the molecular mechanisms of cell responses to low doses of radiation and on the molecular control of genes and gene pathways in microbes. Activities in structural biology include the operation of an experimental station for protein crystallography at LANSCE for use by the national biological research community. LANL conducts research in optical imaging as part of the artificial retina project

In support of BER's climate change research, LANL manages the day-to-day operations at the Tropical Western Pacific Atmospheric Radiation Measurement (ARM) Climate Research Facility (ACRF) site. In addition, LANL manages the deployment and operation of the ACRF mobile facility. LANL also has a crucial role in the development, optimization, and validation of coupled sea ice and oceanic general circulation models and coupling them to atmospheric general circulation models for implementation on massively parallel computers.

LANL is participating in the NSF/DOE Environmental Molecular Sciences Institute at Pennsylvania State University.

- **High Energy Physics**: HEP supports theoretical physics research at LANL, using unique capabilities of the laboratory in high-performance computing for advanced simulations.
- **Nuclear Physics**: NP supports a broad program of research at LANL including: a program of neutron beam research that utilizes beams from the LANSCE facility to make fundamental physics measurements; the fabrication of an experiment to search for the electric dipole moment of the neutron to be located at the Fundamental Neutron Physics Beamline at the Spallation Neutron Source (SNS); a research and development effort in relativistic heavy ions using the PHENIX detector at RHIC and development of next generation instrumentation for RHIC; research directed at the study of the quark substructure of the nucleon in experiments at Fermilab and the "spin" structure of nucleons at RHIC using polarized proton beams; measurement of oscillations of anti-neutrinos with the Mini Booster Neutrino Experiment (MiniBooNE) and reporting results on the properties of neutrinos and R&D directed at future studies of the properties of neutrinos; a broad program of theoretical research; and nuclear data and compilation activities as part of the U.S. Nuclear Data program.
  - At LANL, the 100 MeV Isotope Production Facility (IPF) produces radioactive isotopes, such as germanium-68, a calibration source for positron emission tomography (PET) scanners; strontium-82, the parent of rubidium-82, used in cardiac PET imaging; and arsenic-73, used as a biomedical tracer.
- **Fusion Energy Sciences**: LANL has developed a substantial experimental system for research in magnetized target fusion, one of the major innovative confinement concepts and a thrust area in magnetized high energy density laboratory plasmas. The laboratory leads research in a high-density, compact plasma configuration called field reversed configuration. LANL supports the creation of computer codes for modeling the stability of magnetically confined plasmas, including tokamaks and innovative confinement concepts. The work also provides theoretical and computational support for the Madison Symmetric Torus experiment, a proof-of-principle experiment in reversed field pinch at the University of Wisconsin in Madison. LANL develops advanced diagnostics for the National Spherical Torus Experiment (NSTX) at PPPL and other fusion experiments, such as the rotating magnetic field as a current drive mechanism for the Field Reversed Configuration Experiment at the University of Washington in Seattle. The laboratory is also doing research in inertial electrostatic confinement, another innovative confinement concept. LANL also supports the tritium processing activities needed for ITER.

### National Renewable Energy Laboratory

The National Renewable Energy Laboratory (NREL) is a program-dedicated laboratory located on 632 acres in Golden, Colorado. NREL's focus is on renewable energy technologies such as photovoltaics and other means of exploiting solar energy. It is the world leader in renewable energy technology development. Since its inception in 1977, NREL's mission is to develop renewable energy and energy efficiency technologies and transfer these technologies to the private sector.

- **Basic Energy Sciences**: NREL supports basic research efforts on overcoming semiconductor doping limits, novel and ordered semiconductor alloys, and theoretical and experimental studies of properties of advanced semiconductor alloys for prototype solar cells. It also supports research addressing the fundamental understanding of solid-state, artificial photosynthetic systems. This research includes the preparation and study of novel dye-sensitized semiconductor electrodes, characterization of the photophysical and chemical properties of quantum dots, and study of charge carrier dynamics in semiconductors.
- **Advanced Scientific Computing Research**: NREL participates in SciDAC science application teams including efforts focused on computational nanoscience and computational biology.
- **Biological and Environmental Research:** NREL conducts research on the biological production of hydrogen and is a partner in the Oak Ridge National Laboratory-led Genomic Science BioEnergy Science Center.

### New Brunswick Laboratory

The New Brunswick Laboratory (NBL) is a government-owned, government-operated center for analytical chemistry and measurement science of nuclear materials. In this role, NBL performs measurements of the elemental and isotopic compositions for a wide range of nuclear materials. The NBL is the U.S. Government's Nuclear Materials Measurements and Reference Materials Laboratory and the National Certifying Authority for nuclear reference materials and measurement calibration standards. NBL provides reference materials, measurement and interlaboratory measurement evaluation services, and technical expertise for evaluating measurement methods and safeguards measures in use at other facilities for a variety of Federal program sponsors and customers. The NBL also functions as a Network Laboratory for the International Atomic Energy Agency. The NBL is administered through and is a part of the Chicago Office.

### Oak Ridge Institute for Science and Education

The Oak Ridge Institute for Science and Education (ORISE), operated by Oak Ridge Associated Universities (ORAU), is located on a 169-acre site in Oak Ridge, Tennessee. Established in 1946, ORAU is a university consortium leveraging the scientific strength of major research institutions to advance science and education by partnering with national laboratories, government agencies, and private industry. ORISE focuses on scientific initiatives to research health risks from occupational hazards, assess environmental cleanup, respond to radiation medical emergencies, support national security and emergency preparedness, and educate the next generation of scientists.

- **Basic Energy Sciences**: ORISE provides administrative support for panel reviews and site reviews. It also assists with the administration of topical scientific workshops and provides administrative support for other activities such as for the reviews of construction projects.
- **Advanced Scientific Computing Research**: ORISE provides administrative support for panel reviews, site reviews, and Advanced Scientific Computing Advisory Committee meetings. It also assists with the administration of topical scientific workshops.
- **Biological and Environmental Research**: ORISE coordinates research fellowship programs and coordinates activities associated with the peer review of research proposals and applications.

- **High Energy Physics**: ORISE provides support to the HEP program in the area of program planning and review.
- **Nuclear Physics**: ORISE supports the Holifield Radioactive Ion Beam Facility (HRIBF) and its research program through a close collaboration with university researchers using HRIBF.
- **Fusion Energy Sciences**: ORISE supports the operation of the Fusion Energy Sciences Advisory Committee and administrative aspects of some FES program peer reviews. It also acts as an independent and unbiased agent to administer the FES Graduate and Postgraduate Fellowship programs.
- **Science Laboratories Infrastructure**: SLI enables the cleanup and removal of excess facilities at ORISE.
- **Safeguards and Security**: S&S at ORISE provides physical protection by employing unarmed security officers for the purpose of protecting government-owned assets. The program includes information security, program management, personnel security, protective forces, security systems, and cyber security.
- **Workforce Development:** ORISE manages the DOE-NSF program supporting graduate students to attend the Lindau Meeting of Nobel Laureates.

### Oak Ridge National Laboratory

The Oak Ridge National Laboratory (ORNL) is a multiprogram laboratory located on a 21,000 acre reservation at Oak Ridge, Tennessee. The laboratory's 1,100 acre main site on Bethel Valley Road contains 241 buildings (3.7 million gross square feet of space) with an average building age of 40 years. Scientists and engineers at ORNL conduct basic and applied research and development to create scientific knowledge and technological solutions that strengthen the nation's leadership in key areas of science; increase the availability of clean, abundant energy; restore and protect the environment; and contribute to national security. ORNL provides world-class scientific research capability while advancing scientific knowledge through such major Departmental initiatives as the Spallation Neutron Source (SNS), the supercomputing program, nanoscience research, complex biological systems, and ITER. In the defense mission arena, programs include those which protect our Homeland and National Security by applying advanced science and nuclear technology to the Nation's defense. Through the Nuclear Nonproliferation program, ORNL supports the development and coordination of domestic and international policy aimed at reducing threats, both internal and external, to the U.S. from weapons of mass destruction. ORNL also supports various Energy Efficiency and Renewable Energy programs and facilitates the R&D of energy efficiency and renewable energy technologies.

- **Basic Energy Sciences**: ORNL is home to major research efforts in materials and chemical sciences with additional programs in engineering and geosciences. ORNL has perhaps the most comprehensive materials research program in the country. It is also the site of four BES supported user facilities—the Spallation Neutron Source (SNS), the High Flux Isotope Reactor (HFIR), Shared Research Equipment (SHaRE) User Facility, and the Center for Nanophase Materials Sciences (CNMS).
  - The **Spallation Neutron Source** is a next-generation short-pulse spallation neutron source for neutron scattering that is significantly more powerful (by about a factor of 10) than any other spallation neutron source 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 produced are then used for neutron

scattering experiments. Specially designed scientific instruments use these pulsed neutron beams for a wide variety of investigations. There is initially one target station that can accommodate 24 instruments; the potential exists for adding more instruments and a second target station.

- The **High Flux Isotope Reactor** is a light-water cooled and moderated reactor that 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 HFIR reveal the structure and dynamics of a 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. A number of improvements at HFIR have increased its neutron scattering capabilities to 14 state-of-the-art neutron scattering instruments on the world's brightest beams of steady-state neutrons.
- The **Shared Research Equipment User Facility** 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 have been conducted, such as the characterization of magnetic materials, catalysts, semiconductor device materials, high temperature superconductors, and surface-modified polymers.
- The **Center for Nanophase Materials Sciences** integrates nanoscale science with neutron science; synthesis science; and theory, modeling, and simulation. Scientific themes include macromolecular complex systems, functional nanomaterials such as carbon nanotubes, nanoscale magnetism and transport, catalysis and nano building blocks, and nanofabrication.

- **Advanced Scientific Computing Research**: ORNL conducts basic research in mathematics and computer science, as well as research in advanced computing software tools. ORNL also participates in several SciDAC science application teams, and both SciDAC Centers for Enabling Technologies and SciDAC Institutes that focus on specific software challenges confronting users of petascale computers. The Leadership Computing Facility (LCF) at ORNL is operating the world's most powerful unclassified scientific research high performance computer, a one petaflop Cray Baker system that takes the total capability to 1.64 petaflops peak performance.
- **Biological and Environmental Research**: ORNL has a leadership role in research focused on the ecological aspects of global environmental change. It supports basic research through ecosystem-scale manipulative experiments in the field, laboratory experiments involving model ecosystems exposed to global change factors, and development and testing of computer simulation models designed to explain and predict effects of climatic change on the structure and functioning of terrestrial ecosystems. ORNL is the home of a Free-Air $CO_2$ Enrichment (FACE) experiment which facilitates research on terrestrial carbon processes and the development of terrestrial carbon cycle models. It also houses the ACRF archive, providing data to atmospheric system research scientists and to the general scientific community. ORNL, in conjunction with ANL and PNNL and six universities, plays a principle role in the Carbon Sequestration in Terrestrial Ecosystems (CSiTE) consortium which is focusing on research to enhance the capacity, rates, and longevity of carbon sequestration in terrestrial ecosystems. ORNL scientists provide improvement in formulations and numerical methods necessary to improve climate models.

ORNL scientists make important contributions to the subsurface biogeochemical research activities, providing special leadership in microbiology applied in the field. ORNL also manages environmental remediation sciences research, including a field site for research on advancing the understanding and predictive capability of coupled hydrologic, geochemical, and microbiological processes that control the *in situ* transport, remediation, and natural attenuation of metals, radionuclides, and co-contaminants at multiple scales ranging from the molecular to the watershed.

ORNL is one of the major national laboratory partners that support the JGI, the principal goal of which is high-throughput DNA sequencing. One of ORNL's roles in the JGI involves the annotation (assigning biological functions to genes) of completed genomic sequences and mouse genetics. ORNL conducts research on widely used data analysis tools and information resources that can be automated to provide information on the biological function of newly discovered genes identified in high-throughput DNA sequencing projects. ORNL conducts microbial systems biology research as part of Genomic Science. The **BioEnergy Science Center (BESC)** at ORNL, one of three Genomic Science Bioenergy Research Centers, is focusing attention on two prime candidate feedstock plants, the poplar tree and switchgrass, as well as engineering microbes to enable more efficient biomass conversion by combining several steps.

- **Nuclear Physics**: The major effort at ORNL is the research, development, and operations of the Holifield Radioactive Ion Beam Facility (HRIBF) that is operated as a national user facility. Also supported are a relativistic heavy ion group that is involved in a research program using the PHENIX detector at RHIC and ALICE at the LHC; the development of and research with the Fundamental Neutron Physics Beamline (FNPB) at the Spallation Neutron Source (SNS); a theoretical nuclear physics effort that emphasizes investigations of nuclear structure and astrophysics; nuclear data and compilation activities that support the national nuclear data effort; and a technical effort involved in rare isotope beam development. Enriched stable isotopes are processed at ORNL materials and chemical laboratories. Radioactive isotopes are chemically processed and packaged in hot cells in a radiochemical laboratory and the Radiochemical Engineering Development Center (REDC).

  - The **Holifield Radioactive Ion Beam Facility** is the only radioactive nuclear beam facility in the U.S. to use the isotope separator on-line (ISOL) method and is used annually by about 250 scientists for studies in nuclear structure, dynamics, and astrophysics using radioactive beams. HRIBF accelerates secondary radioactive beams to higher energies (up to 10 MeV per nucleon) than any other facility in the world with a broad selection of ions. HRIBF conducts R&D on targets and ion sources and low energy ion transport for radioactive beams. The capabilities of HRIBF were augmented by the fabrication of the High Power Test Laboratory (HPTL) which provides capabilities unique in the world for the development and testing of new ion source techniques. The fabrication of a second source and transport beam-line (IRIS2) for radioactive ions will improve efficiency and reliability.

  - The **Fundamental Neutron Physics Beamline** (FNPB) at the Spallation Neutron Source (SNS) provides high intensity pulsed beams of cold and ultracold neutrons for fundamental research with neutrons. A new external building as part of the facility will accommodate precision instrumentation to measure the electric dipole moment of the neutron.

  - The **National Nuclear Data Center** is located at ORNL and supports the NP program in the coordination of production, sales and distribution of isotopes across the Nation.

- **Fusion Energy Sciences**: ORNL develops a broad range of components that are critical for improving the research capability of fusion experiments located at other institutions and that are essential for developing fusion as an environmentally acceptable energy source. The laboratory is a leader in fusion materials science, in the theory of heating of plasmas by electromagnetic waves, antenna design, and design and modeling of pellet injectors to fuel the plasma and control the density of plasma particles. The laboratory is also the site of the Controlled Fusion Atomic Data Center and its supporting research programs. While some ORNL scientists are located full-time at off-site locations, others carry out their collaborations with short visits to the host institutions, followed by extensive computer communications from ORNL for data analysis and interpretation, and theoretical studies. ORNL is also a leader in stellarator theory. ORNL hosts the U.S. ITER Project Office and is the lead laboratory managing the U.S. Contributions to ITER Major Item of Equipment (MIE) project.

- **Science Laboratories Infrastructure**: SLI enables DOE research missions at ORNL by funding line item construction to maintain the general purpose infrastructure and the cleanup and removal of excess facilities.
- **Safeguards and Security**: S&S at ORNL includes security systems, information security, cyber security, personnel security, material control and accountability, and program management. Program planning functions at the laboratory provide for short- and long-range strategic planning, and special safeguards plans associated with both day-to-day protection of site-wide security interests and preparation for contingency operations.

### Oak Ridge National Laboratory Site Office

The Oak Ridge National Laboratory Site Office provides the single federal presence with responsibility for contract performance at ORNL. This site office provides an on-site SC presence with authority encompassing contract management, program and project implementation, federal stewardship, and internal operations.

### Oak Ridge Office

The Oak Ridge (OR) Office directly provides corporate support (i.e., procurement, legal, finance, budget, human resources, and facilities and infrastructure) to site offices responsible for program management oversight of four major management and operating laboratories—Oak Ridge National Laboratory, Pacific Northwest National Laboratory, SLAC National Accelerator Laboratory, and Thomas Jefferson National Accelerator Facility. OR also oversees the OR Reservation and other DOE facilities in the City of Oak Ridge. Together on the Reservation and in the City of Oak Ridge there are 35 buildings (237,416 square feet) with an average age of 50 years and a total replacement plant value (RPV) of $42.0 million. The RPV of the roads and other structures on the Reservation is $68.6 million. The administrative, business, and technical expertise of OR is shared SC-wide through the Integrated Support Center concept. The OR Manager is also the single federal official with responsibility for contract performance at the Oak Ridge Institute for Science and Education (ORISE). The Manager provides on-site presence for ORISE with authority encompassing contract management, program and project implementation, federal stewardship, and internal operations.

- **Science Laboratories Infrastructure**: The Oak Ridge Landlord subprogram maintains Oak Ridge Reservation infrastructure such as roads outside plant fences as well as DOE facilities in the town of Oak Ridge, payment in lieu of taxes (PILT), and other needs related to landlord responsibilities.
- **Safeguards and Security**: S&S provides for contractor protective forces for the Federal office building, OSTI, ORISE, and ORNL. This includes protection of a category 1 Special Nuclear Material Facility, Building 3019. Activities include security systems, information security, and personnel security.

**Office of Scientific and Technical Information**

The Office of Scientific and Technical Information (OSTI) fulfills the Department's legislative mandate to provide public access to the unclassified results of DOE's research programs. OSTI also collects, protects, and provides secure access to DOE's classified research outcomes. OSTI has built broad collaborations both within the U.S. and internationally to enable a single point of access to nearly 400 million pages of scientific information. Within the U.S., Science.gov offers simultaneous searching of federal science databases and websites, while WorldWideScience.org performs the same functionality across the R&D results of over 50 countries.

- **Science Laboratories Infrastructure**: SLI enables DOE research missions at OSTI by funding line item construction to maintain the general purpose infrastructure.

**Pacific Northwest National Laboratory**

Pacific Northwest National Laboratory (PNNL) is a DOE multiprogram laboratory located in Richland, Washington that supports DOE's science, national security, energy, and homeland security missions. PNNL operates the William R. Wiley Environmental Molecular Sciences Laboratory (EMSL)—a 224,463 square feet national scientific user facility constructed by DOE that houses 425 people. PNNL also utilizes 23 Federal facilities in the 300 Area of the Hanford Reservation (543,000 square feet of space that house nearly 600 people). These facilities provide nearly 50% of the PNNL's laboratory space and 100% of its nuclear and radiological facilities. In addition, PNNL operates facilities on land owned by its parent organization, Battelle Memorial Institute (494,000 square feet), and leases an additional 775,500 square feet of office space in the Richland area occupied by approximately 2,100 staff.

- **Basic Energy Sciences**: PNNL supports research in interfacial and surface chemistry, inorganic molecular clusters, analytical chemistry, and applications of theoretical chemistry to understanding surface. Geosciences research includes theoretical and experimental studies to improve our understanding of phase change phenomena in microchannels. Also supported is research on stress corrosion and corrosion fatigue, interfacial dynamics during heterogeneous deformation, irradiation assisted stress corrosion cracking, bulk defect and defect processing in ceramics, chemistry and physics of ceramic surfaces, and interfacial deformation mechanisms in aluminum alloys.
- **Advanced Scientific Computing Research**: PNNL conducts basic research in mathematics and computer science, as well as research in advanced computing software tools. PNNL also participates in several SciDAC science application teams and both SciDAC Centers for Enabling Technologies and SciDAC Institutes that focus on specific software challenges confronting users of petascale computers.
- **Biological and Environmental Research**: PNNL is home to EMSL, a national scientific user facility that is an integrated experimental and computational resource for discovery and technological innovation in the environmental molecular sciences to support the needs of DOE and the nation. EMSL provides unique ultra high field mass spectrometry and nuclear magnetic resonance spectrometry instruments, a high performance computer, and a variety of other cutting edge analytical capabilities for use by the national research community.

  PNNL conducts a wide variety of subsurface biogeochemical research, with emphases on biogeochemistry and fate and transport of radionuclides. PNNL is participating in the NSF/DOE Environmental Molecular Sciences Institutes at Pennsylvania State University. It also conducts research into new instrumentation for microscopic imaging of biological systems.

PNNL provides expertise in research on aerosol properties and processes and in field campaigns for atmospheric sampling and analysis of aerosols. PNNL also conducts climate modeling research to improve the simulations of both precipitation through representation of sub-grid orography and the effect of aerosols on climate at regional to global scales. The Atmospheric Radiation Measurement (ARM) Climate Research Facility (ACRF) technical office is located at PNNL, as is the project manager for the ACRF engineering activity; this provides invaluable logistical, technical, and scientific expertise for the program. PNNL manages the ARM Aerial Facility (AAF) as well. PNNL also conducts research on improving atmospheric system research methods and models for assessing the costs and benefits of climate change and of various different options for mitigating and/or adapting to such changes. PNNL, in conjunction with ANL and ORNL and six universities, plays an important role in the CSiTE consortium, focusing on the role of soil microbial processes in carbon sequestration. PNNL also conducts research on the integrated assessment of global climate change.

PNNL is one of the major national laboratory partners that support the JGI, the principal goal of which is high-throughput DNA sequencing. One of PNNL's roles in the JGI involves proteomics research (identifying all the proteins found in cells). PNNL conducts research on the molecular mechanisms of cell responses to low doses of radiation and on the development of high throughput approaches for characterizing all of the proteins (the proteome) being expressed by cells under specific environmental conditions. PNNL conducts microbial systems biology research as part of Genomic Science.

- **Fusion Energy Sciences**: PNNL has focused on research on materials that can survive in a fusion neutron environment. Experienced scientists and engineers at PNNL provide leadership in the evaluation of ceramic matrix composites for fusion applications and support work on ferrite steels as part of the U.S. fusion materials team.
- **Nuclear Physics**: NP supports modest R&D efforts aimed at exploring production mechanisms for isotopes, and for the processing of select isotopes important to the U.S.
- **Science Laboratories Infrastructure**: SLI enables DOE research missions at PNNL by funding line item construction to maintain the general purpose infrastructure and the cleanup and removal of excess facilities.
- **Safeguards and Security**: The PNNL S&S program consists of program management, physical security systems, protection operations, information security, cyber security, personnel security, and material control and accountability.

### Pacific Northwest Site Office

The Pacific Northwest Site Office provides the single federal presence with responsibility for contract performance at PNNL. This site office provides an on-site SC presence with authority encompassing contract management, program and project implementation, federal stewardship, and internal operations.

### Princeton Plasma Physics Laboratory

Princeton Plasma Physics Laboratory (PPPL) is a program-dedicated laboratory located on 88 acres in Plainsboro, New Jersey. The laboratory consists of 34 buildings (754,196 gross square feet of space) with an average building age of 34 years.

- **Advanced Scientific Computing Research**: PPPL participates in SciDAC science application teams related to fusion science.

- **High Energy Physics**: HEP supports a small theoretical research effort at PPPL using unique capabilities of the laboratory in the area of advanced accelerator R&D.
- **Fusion Energy Sciences**: PPPL is the only DOE laboratory devoted primarily to plasma and fusion science. The laboratory hosts experimental facilities used by multi-institutional research teams and also sends researchers and specialized equipment to other fusion facilities in the United States and abroad. PPPL is the host for the National Spherical Torus Experiment (NSTX), which is an innovative toroidal confinement device, closely related to the tokamak. PPPL scientists and engineers have significant involvement in the DIII-D and Alcator C-Mod tokamaks and the NSF Center for Magnetic Self-Organization in Laboratory and Astrophysical Plasmas, as well as several large tokamak facilities abroad, including the Joint European Torus in the United Kingdom, and the Korean Superconducting Tokamak Reactor Advanced Research in Korea. This research is focused on developing the scientific understanding and innovations required for an attractive fusion energy source. PPPL scientists are also involved in several basic plasma science experiments, ranging from magnetic reconnection to plasma processing. PPPL also has a large theory group that does research in the areas of turbulence and transport, equilibrium and stability, wave-plasma interaction, and heavy ion accelerator physics. PPPL, LBNL, and LLNL currently work together in advancing the physics of heavy ion drivers for research in high energy density laboratory plasmas through the Heavy Ion Fusion Science Virtual National Laboratory. Through its association with Princeton University, PPPL provides high quality education in fusion-related sciences, having produced more than 200 Ph.D. graduates since its founding in 1951.
- **Safeguards and Security**: S&S at PPPL provides for protection of special nuclear materials, government property, and other vital assets from unauthorized access, theft, diversion, sabotage, or other hostile acts. The program consists of security officers, security systems, cyber security, and program management.

### Princeton Site Office

The Princeton Site Office provides the single federal presence with responsibility for contract performance at PPPL. This site office provides an on-site SC presence with authority encompassing contract management, program and project implementation, federal stewardship, and internal operations.

### Sandia National Laboratories

Sandia National Laboratories (SNL) is a multiprogram laboratory located on 3,700 acres in Albuquerque, New Mexico (SNL/NM), with additional sites in Livermore, California (SNL/CA), and Tonopah, Nevada.

- **Basic Energy Sciences**: SNL is home to significant research efforts in materials and chemical sciences with additional programs in engineering and geosciences. SNL has a historic emphasis on electronic components needed for Defense Programs. The laboratory has very modern facilities in which unusual microcircuits and structures can be fabricated out of various semiconductors. It is also the site of the Center for Integrated Nanotechnologies (CINT).
  - The **Center for Integrated Nanotechnologies** is devoted to establishing the scientific principles that govern the design, performance, and integration of nanoscale materials. Through its core facility in Albuquerque, New Mexico, and its gateways to both Sandia National Laboratories and Los Alamos National Laboratory, CINT provides access to tools and expertise to explore the continuum from scientific discovery to the integration of nanostructures into the microworld and the macroworld. CINT supports five scientific thrusts that serve as synergistic building blocks

for integration research: nano-bio-micro interfaces, nanophotonics and nanoelectronics, complex functional nanomaterials, nanomechanics, and theory and simulation.

- **Advanced Scientific Computing Research**: SNL conducts basic research in mathematics and computer science, as well as research in advanced computing software tools. SNL also participates in several SciDAC science application teams and both SciDAC Centers for Enabling Technologies and SciDAC Institutes, which focus on specific software challenges confronting users of petascale computers.
- **Biological and Environmental Research**: In support of BER's climate change research, SNL provides the site manager for the North Slope of Alaska ACRF site who is responsible for day-to-day operations at that site. In addition, SNL conducts climate modeling research on modifying the Community Atmospheric Model (CAM) to support new dynamical cores and improve its scalability for implementation on high-system computing systems. The laboratory conducts advanced research and technology development in robotics, smart medical instruments, microelectronic fabrication of the artificial retina, and computational modeling of biological systems.
- **Fusion Energy Sciences**: SNL plays a lead role in developing components for fusion devices through the study of plasma interactions with materials, the behavior of materials exposed to high heat fluxes, and the interface of plasmas and the walls of fusion devices. Material samples and prototypes are tested in SNL's Plasma Materials Test Facility, which uses high-power electron beams to simulate the high heat fluxes expected in fusion environments. Materials and components are exposed to tritium-containing plasmas in the Tritium Plasma Experiment located in the STAR facility at INL. Sandia supports a wide variety of domestic and international experiments in the areas of tritium inventory removal, materials postmortem analysis, diagnostics development, and component design and testing. SNL serves an important role in the design and analysis activities related to the ITER first wall components, including related R&D.

### Savannah River National Laboratory

The Savannah River National Laboratory (SRNL) is a multiprogram laboratory located on approximately 34 acres in Aiken, South Carolina. SRNL provides scientific and technical support for the site's missions, working in partnership with the site's operating divisions.

**Biological and Environmental Research**: SRNL scientists support environmental remediation sciences research program in the area of subsurface contaminant fate and transport.

### SLAC National Accelerator Laboratory

The SLAC National Accelerator Laboratory is located on 426 acres of Stanford University land in Menlo Park, California. SLAC is a laboratory dedicated to the design, construction, and operation of state-of-the-art electron accelerators and related experimental facilities for use in high-energy physics and photon science and has operated the two mile long Stanford Linear Accelerator (linac) since 1966. SLAC consists of 144 buildings (1.8 million gross square feet of space) with the average age of 31 years. SLAC houses the Kavli Institute for Particle Astrophysics and Cosmology (KIPAC), which is an independent laboratory of Stanford University.

- **Basic Energy Sciences**: SLAC is home to research activities in materials and chemical sciences. It is also the site of two user facilities—the Stanford Synchrotron Radiation Light source (SSRL) and the Linac Coherent Light Source (LCLS).

- The **Stanford Synchrotron Radiation Light source** is a DOE user facility for researchers from industry, government laboratories, and universities. These include astronomers, biologists, chemical engineers, chemists, electrical engineers, environmental scientists, geologists, materials scientists, and physicists. A research program is conducted at SSRL with emphasis in both the x-ray and ultraviolet regions of the spectrum. SSRL scientists are experts in photoemission studies of high-temperature superconductors and in x-ray scattering. The SPEAR 3 upgrade at SSRL provided major improvements that increase the brightness of the ring for all experimental stations.

- The **Linac Coherent Light Source** is a user facility that 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. The SLAC linac will provide high-current, low-emittance 5–15 GeV electron bunches at a 120 hertz repetition rate. A long undulator bunches the electrons and leads to self-amplification of the emitted x-ray radiation at the LCLS, which constitutes the world's first free electron laser user facility.

▪ **Advanced Scientific Computing Research**: SLAC participates in SciDAC science application teams relevant to physics research, accelerator modeling, and distributed data.

▪ **Biological and Environmental Research**: SLAC operates nine SSRL beamlines for structural molecular biology. This program involves synchrotron radiation-based research and technology developments in structural molecular biology that focus on protein crystallography, x-ray small angle scattering diffraction, and x-ray absorption spectroscopy for determining the structures of complex proteins of many biological consequences. Beamlines at SSRL also support a growing environmental science user community.

▪ **High Energy Physics**: From 1999 to 2008, SLAC operated the **B-factory,** consisting of PEP-II, a high energy asymmetric electron-positron collider, and BaBar, a multi-purpose detector, for high-precision studies of CP symmetry violation in the B meson system. The BaBar detector collaboration includes about 600 physicists from SLAC and other national laboratories, U.S. universities, and foreign universities and research institutes. Ramp-down and decommissioning and decontamination activities started in FY 2009 and will continue for a number of years.

  SLAC participates in the research program of the ATLAS detector at the Large Hadron Collider, and is also working at the Cosmic Frontier of particle astrophysics. SLAC led construction of the primary instrument for the Fermi Gamma-ray Space Telescope (FGST) which was launched into earth orbit in 2008, and is home to the data operations center that manages the scientific data collection from the satellite. SLAC physicists and a user community will analyze the FGST data through 2012. SLAC is leading the R&D for a camera to be used in the proposed Large Synoptic Survey Telescope, which is a next-generation ground-based dark energy experiment. SLAC and Stanford University are also home to the Kavli Institute for Particle Astrophysics and Cosmology, which brings together researchers studying a broad range of fundamental questions about the universe, from theoretical astrophysics to dark matter and dark energy. High Energy Physics supports research at Kavli aimed primarily at exploring astrophysical phenomena to test new ideas in particle physics.

  SLAC is a major contributor to the leadership and development of advanced accelerator technologies. The laboratory is at the forefront of damping ring and beam delivery designs, required to ensure the beam brightness and precision control needed for future accelerators. SLAC also represents the center of expertise for design, fabrication, and testing of radio frequency power systems used to energize the accelerator components. The laboratory also participates in R&D for advanced detector technologies, with emphasis on software, simulation, and electronics.

- **Science Laboratories Infrastructure**: SLI enables DOE research missions at SLAC by funding line item construction to maintain the general purpose infrastructure and the cleanup and removal of excess facilities.
- **Safeguards and Security**: S&S at SLAC focuses on reducing the risk to DOE national facilities and assets. The program consists primarily of security officers, security systems, program management, and cyber security program elements.

### Stanford Site Office

The Stanford Site Office provides the single federal presence with responsibility for contract performance at SLAC. This site office provides an on-site SC presence with authority encompassing contract management, program and project implementation, federal stewardship, and internal operations.

### Thomas Jefferson National Accelerator Facility

Thomas Jefferson National Accelerator Facility (TJNAF) is a program dedicated laboratory located on 206 acres in Newport News, Virginia, focused on the exploration of nuclear and nucleon structure. The laboratory consists of 63 buildings (684,221 gross square feet of space) with an average building age of 17 years, 2 state-leased buildings, 17 real property trailers, and 14 other structures and facilities.

- **Advanced Scientific Computing Research**: TJNAF participates in SciDAC science application teams relevant to physics research, accelerator modeling, and distributed data.
- **Biological and Environmental Research**: BER supports the development of advanced imaging instrumentation at TJNAF that will ultimately be used in the next generation medical imaging systems.
- **High Energy Physics**: HEP supports an R&D effort at TJNAF on accelerator technology, using the unique expertise of the laboratory in the area of superconducting radiofrequency systems for particle acceleration.
- **Nuclear Physics**: The centerpiece of TJNAF is the **Continuous Electron Beam Accelerator Facility (CEBAF)**, a unique international electron-beam user facility for the investigation of nuclear and nucleon structure based on the underlying quark substructure. The facility has an international user community of about 1,300 researchers. Polarized electron beams up to 5.7 GeV can be provided by CEBAF simultaneously to three different experimental halls. Hall A is designed for spectroscopy and few-body measurements. Hall B has a large acceptance detector, CLAS, for detecting multiple charged particles coming from a scattering reaction. Hall C is designed for flexibility to incorporate a wide variety of different experiments. Its core equipment consists of two medium resolution spectrometers for detecting high momentum or unstable particles. The G0 detector in Hall C allows a detailed mapping of the strange quark contribution to nucleon structure. Also in Hall C, a new detector, Q-weak, is being fabricated to measure the weak charge of the proton by a collaboration of laboratory and university groups, in partnership with the NSF. TJNAF supports a group that does theoretical calculations and investigations in subjects supporting the experimental research programs in Medium Energy Physics. TJNAF research and engineering staff are world experts in superconducting radio frequency accelerator technology; their expertise is being used in the construction of the 12 GeV CEBAF Upgrade project. The 12 GeV CEBAF Upgrade project initiated construction activities in FY 2009 and will provide researchers with the opportunity to study quark confinement, one of the greatest mysteries of modern physics.

- **Science Laboratories Infrastructure**: SLI enables DOE research missions at TJNAF by funding line item construction to maintain the general purpose infrastructure and the cleanup and removal of excess facilities.
- **Safeguards and Security**: TJNAF has security officers that provide 24-hour services for the accelerator site and after-hours property protection security for the entire site. Other security programs include cyber security, program management, material control and accountability, and security systems.

### Thomas Jefferson Site Office

The Thomas Jefferson Site Office provides the single federal presence with responsibility for contract performance at TJNAF. This site office provides an on-site SC presence with authority encompassing contract management, program and project implementation, federal stewardship, and internal operations.

### Washington Headquarters

SC Headquarters, located in the Washington, D.C. area, supports the SC mission by funding Federal staff responsible for SC-wide issues, operational policy, scientific program development, and management functions supporting a broad spectrum of scientific disciplines and program offices. These program offices include ASCR, BES, BER, FES, HEP, and NP, and also include activities conducted by the Workforce Development for Teachers and Scientists program. Additionally, support is included for management of workforce program direction and infrastructure through policy, technical, and administrative support staff responsible for budget and planning; general administration; information technology; infrastructure management; construction management; safeguards and security; and environment, safety, and health within the framework set by the Department. Funded expenses include salaries, benefits, travel, general administrative support services and technical expertise, as well as other costs funded through interdepartmental transfers and interagency transfers.

### Waste Isolation Pilot Plant

The Waste Isolation Pilot Plant is a deep geologic repository for the permanent disposal of radioactive waste; and is located in Eddy County in southeastern New Mexico, 26 miles southeast of Carlsbad.

# Basic Energy Sciences

## Funding Profile by Subprogram (Non-Comparable, or as Appropriated, Structure)

(dollars in thousands)

| | FY 2008 Current Appropriation | FY 2009 Original Appropriation | FY 2009 Adjustments | FY 2009 Current Appropriation | FY 2009 Additional Appropriation[a] | FY 2010 Request |
|---|---|---|---|---|---|---|
| Basic Energy Sciences | | | | | | |
| Materials Sciences and Engineering | 942,744 | 1,129,391 | +4,243[b] | 1,133,634 | +236,798 | 381,112 |
| Chemical Sciences, Geosciences, and Energy Biosciences | 216,747 | 297,113 | -4,243[b] | 292,870 | +154,062 | 338,357 |
| Scientific User Facilities | — | — | — | — | | 811,791 |
| Subtotal, Basic Energy Sciences | 1,159,491 | 1,426,504 | — | 1,426,504 | +390,860 | 1,531,260 |
| Construction | 93,265 | 145,468 | — | 145,468 | +164,546 | 154,240 |
| Total, Basic Energy Sciences | 1,252,756[cd] | 1,571,972 | — | 1,571,972 | +555,406 | 1,685,500 |

## Funding Profile by Subprogram (Comparable Structure to the FY 2010 Request)

(dollars in thousands)

| | FY 2008 Comparable Appropriation | FY 2009 Original Appropriation | FY 2009 Adjustments | FY 2009 Comparable Appropriation | FY 2009 Additional Appropriation[a] | FY 2010 Request |
|---|---|---|---|---|---|---|
| Basic Energy Sciences | | | | | | |
| Materials Sciences and Engineering | 234,429 | 1,129,391 | -787,727[be] | 341,664 | +154,062[e] | 381,112 |
| Chemical Sciences, Geosciences, and Energy Biosciences | 216,747 | 297,113 | -4,243[b] | 292,870 | +154,062 | 338,357 |
| Scientific User Facilities | 708,315 | — | +791,970[be] | 791,970 | +82,736[e] | 811,791 |
| Subtotal, Basic Energy Sciences | 1,159,491 | 1,426,504 | — | 1,426,504 | +390,860 | 1,531,260 |
| Construction | 93,265 | 145,468 | — | 145,468 | +164,546 | 154,240 |
| Total, Basic Energy Sciences | 1,252,756[cd] | 1,571,972 | — | 1,571,972 | +555,406 | 1,685,500 |

**Public Law Authorizations:**
Public Law 95–91, "Department of Energy Organization Act", 1977
Public Law 108–153, "21st Century Nanotechnology Research and Development Act", 2003
Public Law 109–58, "Energy Policy Act of 2005"
Public Law 110–69, "America COMPETES Act of 2007"

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[a] The Additional Appropriation column reflects the planned allocation of funding from the American Recovery and Reinvestment Act of 2009, P.L. 111–5. See the Department of Energy website at http://www.energy.gov/recovery for up-to-date information regarding Recovery Act funding.
[b] Reflects a reallocation of funding in accordance with the explanatory statement for the Energy and Water Development and Related Agencies Appropriations Act, 2009, P.L. 111–8.
[c] Includes $13,500,000 provided by the Supplemental Appropriations Act, 2008, P.L. 110–252.
[d] Total is reduced by $30,646,000: $27,363,000 of which was transferred to the Small Business Innovative Research (SBIR) program and $3,283,000 of which was transferred to the Small Business Technology Transfer (STTR) program.
[e] Adjustments reflect reallocation to the new subprogram, Scientific User Facilities.

Modifications were made to the budget structure to better reflect the subprograms activities in FY 2010. The two tables above show a non-comparable and comparable funding profile for the subprogram. The non-comparable table presents the FY 2010 funding in the new budget structure only and FY 2008 and FY 2009 funding is shown as appropriated. The comparable table shows the FY 2008 and FY 2009 funding in the new budget structure to assist in comparing year-to-year funding trends. A cross-walk of the new and old structure is provided at the end of this chapter, describing in detail the modification to the budget structure.

## Program Overview

### Mission

The mission of the Basic Energy Sciences (BES) program is to support fundamental research to understand, predict, and ultimately control matter and energy at the electronic, atomic, and molecular levels in order to provide the foundations for new energy technologies and to support other aspects of DOE missions in energy, environment, and national security.

### Background

Our ability to discover and transform the material resources that nature provides has shaped history and built civilizations. From prehistoric hunters and gatherers, who utilized wood-burning fires and fashioned tools from stone, to modern nations that run on processes powered primarily by coal and oil, progress has been marked by advanced technologies designed to make better use of our planet's resources. Today, science and technology is even more at the heart of many critical societal, political, and economic issues that surround the energy security and sustainability of our nation.

Fundamentally, the energy challenges of the next century will increasingly involve scientific discovery and technological innovation. The lessons of the previous century illustrate that major breakthroughs in energy technologies are largely built on a solid foundation of research advances. At the core of these advances is our ability to create new materials using sophisticated synthetic and processing techniques and to precisely define the atomic arrangements in matter and control their physical and chemical transformations.

The research disciplines that the BES program supports—condensed matter and materials physics, chemistry, geosciences, and aspects of physical biosciences—are those that discover new materials and design new chemical processes. These disciplines touch virtually every aspect of energy resources, production, conversion, transmission, storage, efficiency, and waste mitigation. BES research provides a knowledge base to help understand, predict, and ultimately control the natural world and serves as an agent of change in achieving the vision of a secure and sustainable energy future.

BES and its predecessor organizations have supported a program of fundamental research focused on critical mission needs of the nation for over five decades. The federal program that became BES began with a research effort initiated to help defend our nation during World War II. The diversified program was organized into the Division of Research with the establishment of the Atomic Energy Commission in 1946 and was later renamed Basic Energy Sciences in 1977 as it continued to evolve through legislation. The program has a rich history of high impact scientific discoveries with unparalleled contributions to mission-critical needs, from radiation-resistant materials to actinide chemistry.

The BES program is one of the nation's largest sponsors of research in the natural sciences. In FY 2008, the program funded research in more than 170 academic institutions located in 50 states and in 13 DOE laboratories located in 9 states. BES supports a large extramural research program, with approximately 40% of the program's research activities sited at academic institutions. The BES program also supports world-class scientific user facilities, providing outstanding capabilities for imaging; for characterizing materials of all kinds from metals, alloys, and ceramics to fragile biological samples; and for studying the chemical transformation of materials. These facilities were supported because of the need to correlate the microscopic structure of materials with their macroscopic properties, lending critical insights to their electronic, atomic, and molecular configurations, often at ultrasmall length and ultrafast time scales.

The energy systems of the future, whether they tap sunlight, store electricity, or make fuel from splitting water or reducing carbon dioxide, will revolve around materials and chemical changes that convert energy from one form to another. Such materials will need to be much smarter and more functional than today's energy materials. To control chemical reactions or to convert a solar photon to an electron requires coordination of multiple steps, each carried out by customized materials with designed nanoscale structures. Such advanced materials are not found in nature like fossil fuels; they must be designed and fabricated to exacting standards using principles revealed by basic science.

The 20$^{th}$ century witnessed revolutionary advances in observational science, bringing remarkable discoveries such as high temperature superconductors, electron microscopy with atomic resolution, and carbon nanotubes that combine the strength of steel with the mass of a feather. Observational science is now giving birth to the science of control, where accumulated knowledge derived from observations is used to design, initiate, and direct the chemical and physical behavior of materials at atomic and nanoscales. BES-supported research stands at the dawn of an age in which materials can be built with atom-by-atom precision and computational models can predict the behavior of non-existing materials before they are made. These capabilities, unthinkable only a few decades ago, create unprecedented opportunities to revolutionize the future of sustainable energy applications and beyond, from information management to national security.

**Subprograms**

To accomplish its mission and address the scientific challenges outlined above, the BES program is organized into three subprograms: Materials Sciences and Engineering; Chemical Sciences, Geosciences, and Energy Biosciences; and Scientific User Facilities.

The *Materials Sciences and Engineering* subprogram supports research that explores the origin of macroscopic material behaviors and their fundamental connections to atomic, molecular, and electronic structures. At the core of the subprogram is the quest for a paradigm shift for the deterministic design and discovery of new materials with novel structures, functions, and properties. To accomplish this goal, the portfolio stresses the need to probe, understand, and control the interactions of phonons, photons, electrons, and ions with matter to direct and control energy flow in materials systems over multiple time and length scales. Such understanding and control are critical to designing highly efficient energy conversion processes, such as new electromagnetic pathways for enhanced light emission in solid-state lighting and multi-functional nanoporous structures for optimum charge transport in batteries and fuel cells. This subprogram also seeks to conceptualize, calculate, and predict processes underlying physical transformations, tackling challenging real-world systems—for example, materials with many atomic constituents, with complex architectures, or that contain defects; systems that exhibit correlated emergent behavior; systems that are far from equilibrium. Such understanding will be critical to developing predictive capability for complex systems behavior, such as in superconductivity and magnetism. The subprogram also supports the development and advancement of the experimental and computational tools and techniques that in turn enable the understanding of the behaviors of materials, especially their reactivity under the full range of extreme conditions and the ability to predict the structure of formed phases. Finally, the subprogram exploits the interfaces between physical and biological sciences to explore bio-mimetic processes as new approaches to novel materials design. This subprogram will also support an Energy Innovation Hub focused on Batteries and Energy Storage. The

Hub will support large-scale, multidisciplinary team efforts to focus on nurturing and harnessing science to solve our most critical energy problems. The vision for a secure and sustainable energy future entails transitioning from our reliance on foreign fossil fuels to the development, deployment and export of new carbon-free energy technologies invented and manufactured in the U.S. The traditional linear model of discovery science leading to technology development and deployment will not meet the challenge of timeliness and scale. Rather, there is a need for bold and innovative approaches that better couple all of the elements of the science and technology chain and combine the talents of universities, national labs, and the private sector in concerted efforts to define and construct a sustainable energy economy. The Hub approach is designed to integrate a major national mobilization of basic energy research with appropriate investments in engineering and technology to accelerate bringing energy solutions to market.

The *Chemical Sciences, Geosciences, and Energy Biosciences* subprogram supports research that explores fundamental aspects of chemical reactivity and energy transduction over an enormous range of scale and complexity. Phenomena are studied over spatial scales from the sub-nanometer, as defined by the structure of atoms and molecules, to kilometers, appropriate to the behavior of subsurface geological structures, and over time scales defined by the motions of electrons in atoms, attoseconds ($10^{-18}$ seconds), to millennia over which geological change must be understood. At the heart of this research lies the quest to understand and control chemical reactions and the transformation of energy at the molecular scale in systems ranging from simple atoms and molecules, to active catalysts, to complex biochemical or geochemical moieties. At the most fundamental level, the development and understanding of the quantum mechanical behavior of electrons, atoms, and molecules in the 20th century has now evolved into our ability to control and direct such behavior to achieve desired results, such as the optimal conversion of solar energy into electronic excitation in molecular chromophores or into the creation of multiple charge carriers in nanoscale semiconductors. This subprogram also seeks to extend this era of 21st century control science to include the capability to tailor chemical transformations with atomic and molecular precision. Here, the goal is fully predictive capability for larger, more complex chemical systems, such as interfacial catalysis, at the same level of detail now known for simple molecular systems. Finally, this subprogram seeks ultimately to extend a molecular level understanding and control to the emergent and highly non-equilibrium behavior of biological and geological systems through the application of modern experimental and computational tools. This subprogram will also support an Energy Innovation Hub focused on Fuels from Sunlight. This Hub will support large-scale, multidisciplinary team efforts to focus on nurturing and harnessing science to solve our most critical energy problems. The vision for a secure and sustainable energy future entails transitioning from our reliance on foreign fossil fuels to the development, deployment and export of new carbon-free energy technologies invented and manufactured in the U.S. The traditional linear model of discovery science leading to technology development and deployment will not meet the challenge of timeliness and scale. Rather, there is a need for bold and innovative approaches that better couple all of the elements of the science and technology chain and combine the talents of universities, national labs, and the private sector in concerted efforts to define and construct a sustainable energy economy. The Hub approach is designed to integrate a major national mobilization of basic energy research with appropriate investments in engineering and technology to accelerate bringing energy solutions to market.

The *Scientific User Facilities* subprogram supports the operation of a nationwide suite of major facilities that provides open access to sophisticated instrumentation needed to probe and create materials for scientists of many disciplines from academia, national laboratories and industry. These large-scale user facilities consist of a complementary set of intense x-ray sources, neutron scattering centers, electron beam characterization capabilities, and research centers for nanoscale science. These facilities probe materials in space, time, and energy with the appropriate resolutions that can interrogate the inner workings of matter—transport, reactivity, fields, excitations, and motion—to answer some of the most challenging grand science questions. Taking advantage of the intrinsic charge, mass, and magnetic characteristics of x-rays, neutrons, and electrons, these tools offer unique capabilities to help understand the fundamental aspects of the natural world. The subprogram recognizes that at the heart of scientific discovery lies the development of new tools and instruments. The continual advancement and renovation of the instrumental capabilities include developments of new x-ray and neutron experimental stations, improved core facilities, and new stand-alone instruments. The subprogram also manages a research portfolio in accelerator and detector development to explore technology options for developing the next generations of x-ray and neutron sources. Collectively, these user facilities and enabling tools produce a host of important research results that span the continuum from basic to applied research and embrace the full range of scientific and technological endeavors, including chemistry, physics, geology, materials science, environmental science, biology, and biomedical science. These capabilities offer critical scientific insights to enable the discovery and design of advanced materials and novel chemical processes with broad societal impacts, from energy applications to information and biomedical technologies.

**Benefits**

The BES program supports basic research that underpins a broad range of energy technologies. Research in materials sciences and engineering leads to the development of materials that improve the efficiency, economy, environmental acceptability, and safety of energy generation, conversion, transmission, storage, and use. For example, research on toughened ceramics results in improved high-speed cutting tools, engine turbines, and a host of other applications requiring lightweight, high-temperature materials. Research in chemistry leads to the development of advances such as efficient combustion systems with reduced emissions of pollutants; new solar photoconversion processes; improved catalysts for the production of fuels and chemicals; and better separations and analytical methods for applications in energy processes, environmental remediation, and waste management. Research in geosciences results in advanced monitoring and measurement techniques for reservoir definition and an understanding the fluid dynamics of complex fluids through porous and fractured subsurface rock. Research in the molecular and biochemical nature of photosynthesis aids the development of solar photo-energy conversion.

The BES program also plays a major role in enabling the nanoscale revolution. The importance of nanoscience to future energy technologies is clearly reflected by the fact that all of the elementary steps of energy conversion (e.g., charge transfer, molecular rearrangement, and chemical reactions) take place on the nanoscale. The development of new nanoscale materials, as well as the methods to characterize, manipulate, and assemble them, creates an entirely new paradigm for developing new and revolutionary energy technologies.

Looking to the future, eliminating our half-century-long dependence on imported oil and halting our emission of carbon dioxide requires fundamental changes in the ways we produce, store, and use energy. Three strategic goals for which transformational science breakthroughs are needed have been identified in the recent BESAC report *New Science for a Secure and Sustainable Energy Future*: making fuels from sunlight, generating electricity without carbon dioxide emissions, and revolutionizing energy efficiency and use. Achieving these visionary goals will require the development of fundamentally new technologies with performance levels far beyond those that are now possible.

Future technologies based on transformational scientific discoveries may be able to convert sunlight to electricity with triple today's efficiency, store electricity in batteries or supercapacitors at ten times today's capacity, or produce electricity from coal and nuclear plants at twice today's efficiency while capturing and sequestering the carbon dioxide emissions and hazardous radioactive wastes. Accomplishing such technology breakthroughs will only be possible with fundamental understanding of new materials and chemical processes that govern the transfer of energy between light, electricity, and chemical fuels.

A working transistor was only developed after the theory of electronic behavior on semiconductor surfaces was formulated. Lasers were only developed after the quantum theory of light emission by materials was understood. Similar breakthroughs can only be achieved for sustainable energy technologies when matter and energy can be systematically controlled at the electronic, atomic and molecular level in order to design advanced materials and direct desired chemical reactions. A series of such advances—requiring a national mobilization of basic energy research endeavors—are needed for moving beyond incremental improvements to create a truly secure and sustainable energy future.

**Program Planning and Management**

Inputs to program planning and prioritization include overall scientific opportunity, projected investment opportunity, DOE mission need, and Administration and Departmental priorities. Many long-range planning exercises for elements of the BES program are performed under the auspices of the Basic Energy Sciences Advisory Committee (BESAC). During the past few years, BESAC has provided advice on new directions in nanoscale science and complex systems; on the operation of the major scientific user facilities; on the need for new, next-generation facilities for x-ray, neutron, and electron-beam scattering; on performance measurement; on the quality of the BES program management and its consequent impacts on the program portfolio; on new directions in research relating to specific aspects of fundamental science such as catalysis, biomolecular materials, and computational modeling at the nanoscale; on the fundamental research challenges posed by the Department’s energy missions; on a 20-year roadmap for BES facilities; and on theory and computation needs across the entire portfolio of BES research.

Of particular note is the 2003 BESAC report, *Basic Research Needs to Assure a Secure Energy Future*, which was the foundation for ten follow-on *Basic Research Needs* workshops supported by BES in the past six years in the areas of the hydrogen economy; solar energy utilization; superconductivity; solid-state lighting; advanced nuclear energy systems; combustion of 21$^{st}$ century transportation fuels; electrical-energy storage; geosciences as it relates to the storage of energy wastes (the long-term storage of both nuclear waste and carbon dioxide); materials under extreme environments; and catalysis for energy applications. Together these workshops attracted over 1,500 participants from universities, industry, and DOE laboratories. BESAC was recently charged with summarizing the results of these ten workshops and relating this summary to the science themes identified in the 2007 BESAC Grand Challenges study. A report, entitled *New Science for a Secure and Sustainable Energy Future*, was released in December 2008. The report highlighted the magnitude of the challenges in the realm of energy and environment facing the U.S and the importance of fundamental science to finding transformational solutions.

Together these reports describe a continuum of research spanning the most fundamental questions of how nature works to the questions that address technological show-stoppers in the applied research programs supported by the DOE technology offices. Dealing with these issues requires breakthrough advances with new understanding, new materials, and new phenomena that will come from fundamental science. The BES program’s portfolios have been reassessed and restructured as necessary to reflect the results of these workshops. In addition to the work described in these workshops, other priority areas have been identified to highlight grand science challenges, including general support for ultrafast science, chemical imaging, and mid-scale instrumentation.

Planning for the facilities of the BES program is also an ongoing activity. The BES program has a long tradition of planning, constructing, and operating facilities well. During the past ten years, the BES program has delivered nearly $2 billion of facilities and upgrades on schedule and within budget. Among others, this includes the Spallation Neutron Source, the complete reconstruction of the Stanford Synchrotron Radiation Light Source, five Nanoscale Science Research Centers, and numerous instrument fabrication projects. The 2003 Office of Science report, *Facilities for the Future of Science: A Twenty-Year Outlook*, and the 2007 updated interim report, described the long-range plan for the Office of Science facilities.

Recently, BESAC has been charged to sponsor a Photon Workshop to explore the scientific frontiers that could be tackled with next generation photon sources. The workshop will identify new energy and scientific opportunities in materials, chemistry, biology, medicine, environment, and physics that can be addressed with diffraction, excitation, and imaging by photons. It is expected that this workshop will help set the course for photon science facilities for the next decade.

All research projects supported by BES undergo regular peer review and merit evaluation based on procedures set down in 10 CFR Part 605 for the extramural grant program and in an analogous process for the laboratory programs and scientific user facilities. The BES peer review process evaluates the following four criteria, in order of decreasing importance: scientific and/or technical merit of the project; appropriateness of the proposed method or approach; competency of the personnel and adequacy of proposed resources; and reasonableness and appropriateness of the proposed budget. The criteria for review may also include other appropriate factors established and announced by BES.

Facilities are reviewed using external, independent review committees operating according to the procedures established for peer review of BES laboratory programs and facilities. Important aspects of the reviews include assessments of the quality of research performed at the facility, the reliability and availability of the facility, user access policies and procedures, user satisfaction, facility staffing levels, R&D activities to advance the facility, management of the facility, and long-range goals of the facility. The outcomes of these reviews helped improve operations and develop new models of operation for existing light sources, the Spallation Neutron Source, and the National Synchrotron Light Source-II (NSLS-II), which began construction in FY 2009.

Facilities that are in design or construction are reviewed according to procedures set down in DOE Order 413.3A “Program and Project Management for Capital Assets” and in the Office of Science “Independent Review Handbook”[a]. In general, once a project has entered the construction phase, it is reviewed with external, independent committees approximately biannually. These Office of Science construction project reviews enlist experts in the technical scope of the facility under construction and its costing, scheduling, and construction management.

Information and reports for all of the above mentioned advisory and consultative activities are available on the BESAC website[b]. Other studies are commissioned as needed using the National Academies’ National Research Council and other independent groups.

### Basic and Applied R&D Coordination

As is demonstrated by the depth and scope of the *Basic Research Needs* workshop series, the BES program is committed to R&D integration. These workshops and the follow-on solicitations seek to partner the BES program with its counterparts in the DOE technology offices and the defense program. Many activities facilitate cooperation and coordination between BES and the applied research programs,

[a] http://www.science.doe.gov/opa/PDF/revhndbk.pdf
[b] http://www.science.doe.gov/bes/BESAC/BESAC.htm

including joint efforts in strategic planning, solicitation development, peer reviews, and program contractors meetings. For example, in hydrogen research, BES has actively engaged with the Office of Energy Efficiency and Renewable Energy, Fossil Energy, and Nuclear Energy to coordinate activities such as budget submissions, solicitation topic selections and proposal reviews, posture plan development, and joint contractors meetings. BES also participates in interagency coordination activities, such as the Interagency Working Group on Hydrogen and Fuel Cells led by the White House Office of Science and Technology Policy; the Hydrogen Technical Advisory Committee (HTAC), a Federal Advisory Committee established by the Energy Policy Act of 2005 to advise the Secretary of Energy on issues related to hydrogen and fuel cell research, development, demonstration, and deployment; and the Hydrogen and Fuel Cell Interagency Task Force consisting of senior agency representatives across the federal government. BES also coordinates with the Office of Energy Efficiency and Renewable Energy and the Office of Electricity Delivery and Energy Reliability on electrical energy storage research for transportation and grid-level storage, respectively. BES has involved program managers in both offices in regular information exchange meetings and in developing a preliminary coordination plan in electrical energy storage. Since FY 2007, BES has worked with the Office of Electricity Delivery and Energy Reliability to initiate SBIR awards in electrical energy storage for grid applications.

At the program manager level, there have been regular intra-departmental meetings for information exchange and coordination on solicitations, program reviews and project selections in research areas such as biofuels derived from biomass; solar energy utilization; hydrogen production, storage, and use; building technologies, including solid-state lighting; advanced nuclear energy systems and advanced fuel cycle technologies; vehicle technologies; improving efficiencies in industrial processes; and superconductivity for grid applications. These activities facilitate cooperation and coordination between BES and the technology offices and the defense program. DOE program managers have also established formal technical coordinating committees (e.g. the Energy Materials Coordinating Committee) that meet on a regular basis to discuss R&D programs with wide applications for basic and applied programs. Additionally, technology offices staff participate in reviews of BES research, and BES staff participate in reviews of research funded by the technology offices.

The Department’s national laboratory system plays an important role in the ability of BES to effectively integrate research and development by providing opportunities to collocate activities at the laboratories. Co-funding and co-siting of research by BES and DOE technology programs at the same institutions, such as the DOE laboratories or universities, has proven to be a valuable approach to facilitate close integration of basic and applied research. In these cases, teams of researchers benefit by sharing of resources, expertise, and knowledge of research breakthroughs and program needs.

### Budget Overview

The FY 2010 budget request provides targeted increases and sets new directions in two key components in the BES program: research that advances understanding of the natural world and addresses the DOE mission; and enabling tools—the operation and construction of scientific user facilities and the development of unique instruments for the nation.

BES research is broadly supported via three main types of awards—core research, Energy Frontier Research Centers (EFRCs), and Energy Innovation Hubs. These funding mechanisms constitute an increasing progression of scientific scope and level of effort. The thousands of BES core research awards permit individual scientists and small groups to pursue to their specific energy-related research interests. The dozens of EFRC awards bring together multiple investigators to address major scientific challenges necessary to solve complex energy research problems. The two Hub awards will focus multiple teams of researchers—each working in separate but collaborative research areas—on overcoming the related scientific barriers to development of a complete energy system that has potential for implementation into a transformative energy technology.

- *BES core research*—primarily supporting single principal investigator and small group projects—will be continued and expanded to initiate promising new activities in research areas in response to the five grand challenges identified in the BESAC Grand Challenges report: quantum control of electrons in atoms, molecules, and materials; basic architecture of matter; directed assemblies, structure, and properties; emergence of collective phenomena; energy and information on the nanoscale; and matter far beyond equilibrium.
- *Energy Frontier Research Centers (EFRCs)*, were established in FY 2009 to integrate the talents and expertise of leading scientists in a setting designed to accelerate research toward meeting our critical energy challenges. The EFRCs harness the most basic and advanced discovery research in a concerted effort to establish the scientific foundation for a fundamentally new U.S. energy economy. EFRCs bring together critical masses of researchers to conduct fundamental energy research in a new era of grand challenge science and use-inspired energy research. The scientific directions of the EFRCs are overseen by program staff in the Materials Sciences and Engineering Division and the Chemical Sciences, Geosciences, and Biosciences Division, who will be managed centrally within BES to ensure a unified management strategy and structure. In FY 2010, no funding increases are requested for the EFRCs. Instead, emphasis is being placed on ensuring that the EFRCs established late in FY 2009 are progressing toward their full collaborative and scientific potential.
- *Energy Innovation Hubs* are part of a set of Hubs that will be initiated by the Department in FY 2010. The set of Hubs aim at assembling multidisciplinary teams to address the basic science, technology, economic, and policy issues hindering the nation's secure and sustainable energy future. Because the components and processes of energy systems are highly interdependent, innovative solutions to real-world energy challenges will require concerted efforts that couple the various elements of the technology chain and combine the talents of universities, national laboratories, and the private sector. Two Hubs are proposed in BES in FY 2010: Fuels from Sunlight and Batteries and Energy Storage.

The FY 2010 budget request provides continued support for the operations of the suite of BES scientific user facilities, including four x-ray synchrotron sources, three neutron sources and five nanoscale science research centers. The total request represents an average of 3% increase over the FY 2009 funding level, and provides optimal support for the user operations, accounting for cost of living increases. FY 2010 continues the commissioning of the Linac Coherent Light Source (LCLS) at SLAC National Accelerator Laboratory, which 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, with pulse lengths of femtoseconds—the timescale of atomic motion. These facilities provide key capabilities for the fabrication of novel materials, for the examination of materials and their transformations at the atomic scale, and to enable scientists to correlate microscopic structures to macroscopic properties.

Recognizing that at the heart of discovery often lies with the development of new tools and instruments, BES continues to support the planning, R&D, and construction of new scientific user facilities and the associated enabling tools. The new generations of instruments will naturally bring forth devices to direct matter at the levels of electrons, atoms, or molecules, as highlighted in the BESAC Grand Challenges report. The construction activities include the Linac Coherent Light Source (LCLS) at SLAC National Acceleratory Laboratory and the National Synchrotron Light Source II (NSLS-II) at Brookhaven National Laboratory. NSLS-II will continue its construction phase, including the largest component of the project—the building that will house the accelerator ring.

The Spallation Neutron Source Instruments-Next Generation (SING-I and SING-II) will be fully funded according to planned schedules and funding profiles. The Power Upgrade Project, as part of the planned upgrades to the Spallation Neutron Source at Oak Ridge National Laboratory, will be initiated.

### Significant Program Shifts

Two Energy Innovation Hubs are initiated in FY 2010 in the topical areas of Fuels from Sunlight and Batteries and Energy Storage. Each Hub will be funded at $25,000,000 per year for an initial period of 5 years. One-time funding of $10,000,000 will be provided for Hub start-up needs, excluding any new construction

### Strategic and GPRA Unit Program Goals

The BES program has one Government Performance and Results Act (GPRA) Unit Program goal which contributes to Strategic Goal 3.1 and 3.2 in the “goal cascade”:

- GPRA Unit Program Goal 3.1/2.50.00: Advance the Basic Science for Energy Independence – Provide the scientific knowledge and tools to achieve energy independence, securing U.S. leadership and essential breakthroughs in basic energy sciences.

### Contribution to GPRA Unit Program Goal 3.1/2.50.00, Advance the Basic Science for Energy Independence

Within the Basic Energy Sciences program, the Materials Science and Engineering subprogram, the Chemical Sciences, Geosciences, and Energy Biosciences subprogram, and the Scientific User Facilities subprogram contribute to this goal by producing seminal advances in the core disciplines of the basic energy sciences. These subprograms build leading research programs that provide world-class, peer-reviewed research results cognizant of both DOE mission needs and new scientific opportunities. The following indicators establish specific long-term (ten-year) goals in scientific advancement that the BES program is committed to and against which progress can be measured.

- Design, model, fabricate, characterize, analyze, assemble, and use a variety of new materials and structures, including metals, alloys, ceramics, polymers, biomaterials and more—particularly at the nanoscale—for energy-related applications.
- Understand, model, and control chemical reactivity and energy transfer processes in the gas phase, in solutions, at interfaces, and on surfaces for energy-related applications, employing lessons from inorganic, organic, self-assembling, and biological systems.
- Develop new concepts and improve existing methods for major energy research needs identified in the 2003 Basic Energy Sciences Advisory Committee workshop report, Basic Research Needs to Assure a Secure Energy Future.
- Conceive, design, fabricate, and use new scientific instruments to characterize and ultimately control materials.

## Annual Performance Results and Targets

| FY 2005 Results | FY 2006 Results | FY 2007 Results | FY 2008 Results | FY 2009 Targets | FY 2010 Targets |
|---|---|---|---|---|---|
| GPRA Unit Program Goal 3.1/2.50.00 (Advance the Basic Science for Energy Independence) | | | | | |
| Scientific User Facilities | | | | | |
| Improve Spatial Resolution: Spatial resolution for imaging in the hard x-ray region was measured at 90 nm and in the soft x-ray region was measured at 15 nm, and spatial information limit for an electron microscope of 0.078 nm was achieved. [Met Goal] | Improve Spatial Resolution: Spatial resolution for imaging in the hard x-ray region was measured at 90 nm and in the soft x-ray region was measured at 15 nm, and spatial information limit for an electron microscope of 0.078 nm was achieved. [Met Goal] | Improve Spatial Resolution: Spatial resolution for imaging in the hard x-ray region was measured at 90 nm and in the soft x-ray region was measured at 15 nm, and spatial information limit for an electron microscope of 0.078 nm was achieved. [Met Goal]. | Improve Spatial Resolution: Spatial resolution for imaging in the hard x-ray region was measured at 90 nm and in the soft x-ray region was measured at 15 nm, and spatial information limit for an electron microscope of 0.078 nm was achieved. [Met Goal]. | Maintain spatial resolutions for imaging in the hard x-ray region of <100 nm and in the soft x-ray region of <18 nm, and spatial information limit for an electron microscope of 0.08 nm.[a] | Maintain spatial resolutions for imaging in the hard x-ray region of <100 nm and in the soft x-ray region of <18 nm, and spatial information limit for an electron microscope of 0.08 nm.[a] |
| Improve temporal resolution: X-ray pulses were measured at 70 femtoseconds in duration with an intensity of 100 million photons per pulse. [Met Goal] | Improve temporal resolution: X-ray pulses were measured at 70 femtoseconds in duration with an intensity of 100 million photons per pulse. [Met Goal] | Improve temporal resolution: X-ray pulses were measured at 70 femtoseconds in duration with an intensity of 100 million photons per pulse. [Met Goal] | Improve temporal resolution: X-ray pulses were measured at 70 femtoseconds in duration with an intensity of 100 million photons per pulse. [Met Goal] | Maintain x-ray pulses that are <100 femtoseconds in duration and have an intensity of >100 million photons per pulse ($>10^8$ photons/pulse).[a] | Maintain x-ray pulses that are <100 femtoseconds in duration and have an intensity of >100 million photons per pulse ($>10^8$ photons/pulse).[a] |
| Scientific user facilities were maintained and operated to achieve an average at least 90% of the total scheduled operating time (Results: 97.7%). [Met Goal] | Scientific user facilities were maintained and operated to achieve an average at least 90% of the total scheduled operating time (Results: 96.7%). [Met Goal] | Scientific user facilities were maintained and operated to achieve an average at least 90% of the total scheduled operating time (Results: 102.1%). [Met Goal] | Scientific user facilities were maintained and operated to achieve an average at least 90% of the total scheduled operating time (Results: 101.9%). [Met Goal] | Achieve an average operation time of the scientific user facilities as a percentage of the total scheduled annual operating time of greater than 90%. | Achieve an average operation time of the scientific user facilities as a percentage of the total scheduled annual operating time of greater than 90%. |
| Chemical Sciences, Geosciences, and Energy Biosciences | | | | | |
| As a part of the Scientific Discovery through Advanced Computing (SciDAC) program, a three-dimensional combustion reacting flow simulation was performed involving 11 reacting species and 0.5 billion grid points. [Met Goal] | As a part of the Scientific Discovery through Advanced Computing (SciDAC) program, a three-dimensional combustion reacting flow simulation was performed involving 33 reacting species and 21.2 million grid points. [Met Goal] | Improve Simulation: Beginning in FY 2007, increasing the size of the simulation will no longer provide useful new information. Thus, this measure was discontinued. | | | |

[a] No further improvement is expected in FY 2008-FY 2013 for these measures, because the current suite of instruments has met the maximum performance level. This target is a measure of SC's intent to maintain the maximum level of performance for users of the current SC facilities until the next generation of instruments and facilities becomes available.

| FY 2005 Results | FY 2006 Results | FY 2007 Results | FY 2008 Results | FY 2009 Targets | FY 2010 Targets |
|---|---|---|---|---|---|
| Construction | | | | | |
| Cost and timetables were maintained within 10% of the baselines given in the construction project datasheets for all construction projects ongoing during the year (Results: +0.2% cost variance and -2.5% schedule variance). [Met Goal] | Cost and timetables were maintained within 10% of the baselines given in the construction project datasheets for all construction projects ongoing during the year (Results: -1.7% cost variance and -3.2% schedule variance). [Met Goal] | Cost and timetables were not maintained within 10% of the baselines given in the construction project datasheets for all construction projects ongoing during the year (Results: -2.7% cost variance and -10.4% schedule variance). [Goal of <10% Variance Not Met] | Cost and timetables were maintained within 10% of the baselines given in the construction project datasheets for all construction projects ongoing during the year (Results: 1.0% cost variance and -1.4% schedule variance). [Goal Met] | Cost-weighted mean percent variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects. In FY 2009, it is less than 10% and 10%, respectively. | Cost-weighted mean percent variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects. In FY 2010, it is less than 10% and 10%, respectively. |

## Materials Sciences and Engineering

### Funding Schedule by Activity[a]

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Materials Sciences and Engineering | | | |
| Materials Sciences and Engineering Research | 234,429 | 332,833 | 371,190 |
| SBIR/STTR | — | 8,831 | 9,922 |
| Total, Materials Sciences and Engineering | 234,429 | 341,664 | 381,112 |

## Description

This subprogram supports fundamental experimental and theoretical research to provide the knowledge base for the discovery and design of new materials with novel structures, functions, and properties.

In condensed matter and materials physics—including activities in experimental condensed matter physics, theoretical condensed matter physics, materials behavior and radiation effects, and physical behavior of materials—research is supported to understand, design, and control materials properties and function. These goals are accomplished through studies of the relationship of materials structures to their electrical, optical, magnetic, surface reactivity, and mechanical properties and the way in which materials respond to external forces such as stress, chemical and electrochemical environments, radiation, and the proximity of materials to surfaces and interfaces. The activity emphasizes correlation effects, which can lead to the formation of new particles, new phases of matter, and unexpected phenomena. The theoretical efforts include research on the development of advanced computer algorithms and codes to treat large or complex systems.

In scattering and instrumentation sciences—including activities in neutron and x-ray scattering and electron and scanning microscopies—research is supported on the fundamental interactions of photons, neutrons, and electrons with matter to understand the atomic, electronic, and magnetic structures and excitations of materials and the relationship of these structures and excitations to materials properties and behavior. Major research areas include fundamental dynamics in complex materials, correlated electron systems, nanostructures, and the characterization of novel systems. The development of next-generation neutron, x-ray, and electron microscopy instrumentation is a key element of this portfolio.

In materials discovery, design, and synthesis—including activities in synthesis and processing science, materials chemistry, and biomolecular materials—research is supported in the discovery and design of novel materials and the development of innovative materials synthesis and processing methods. Major research thrust areas include nanoscale synthesis, organization of nanostructures into macroscopic structures, solid state chemistry, polymers and polymer composites, surface and interfacial chemistry including electrochemistry and electro-catalysis, synthesis, and processing science including biomimetic and bioinspired routes to functional materials and complex structures.

The proposed Energy Innovation Hub focused on Batteries and Energy Storage will consist of multidisciplinary teams of experts that blend basic scientific research with technology development,

[a] This table shows the FY 2008 and FY 2009 funding in the new (comparable) budget structure to assist in comparing year-to-year funding trends. A crosswalk of the new and old structure is provided at the end of this chapter, describing in detail the modification to the budget structure.

engineering design, and energy policy. They will bridge the gap between basic scientific breakthroughs and industrial commercialization through proof-of-concept prototyping, modeling, measurement, and verification of the potential for major impacts.

**Selected FY 2008 Research Accomplishments**

- *DNA directed fabrication of 3-D nanomaterials*. DNA has been used for the first time to create three-dimensional, ordered, crystalline structures of nanoparticles, which could not be fabricated using conventional techniques. The ability to engineer 3-D structures from nanoscale building blocks is essential to producing practical functional materials that take advantage of the unique properties of nano-objects, e.g., enhanced magnetism, improved catalytic activity, or new optical properties, but the nano-scale precision required makes them difficult to produce. This strategy utilizes nature-derived bio-molecules and takes advantage of their highly specific and well controlled recognitions to precisely direct the organization of inorganic nano-objects. It is particularly attractive as an inexpensive, scalable, and precise method for material fabrication and can provide a powerful means for assembly of individual nanoscale objects into designed architectures with unique physical properties. The research demonstrated the role of DNA design in the formation of such ordered nano-structures, thus providing the way for creation of new classes of novel nanomaterials by design.
- *Breakthrough in solar cell power output via organic solar concentrators***.** A tenfold increase in the amount of power converted by solar cells has been demonstrated via the use of organic solar concentrators. The increase in efficiency is achieved through the novel use of organic dyes and optical wave guides to efficiently absorb and trap the incident solar radiation until it can reach a solar cell. The new organic solar concentrators consist of a layer of transparent glass onto which multiple thin layers of organic dye molecules are deposited. Typically only part of the light spectrum can be utilized by solar cells to create electricity but these dyes act to absorb light across a broader spectrum of wavelengths, thereby increasing efficiency. Specific tailoring of these dyes allows light to be absorbed across the face of the glass, and then re-emitted by the dye molecules at a specific wavelength so that most of the energy stays in the pane of the glass (like a waveguide) and is emitted only at the edge. Small solar cells are then attached along the edges of the glass panel enabling the collection of a large portion of the solar spectrum over full surface of the glass panel yet only requiring small solar collectors, resulting in a further increase in geometric efficiency.
- *Ultrafast x-ray study enables real-time measurement and control of materials in extreme environments.* Using femtosecond x-ray probe pulses, atomic-scale resolution snapshots of complex nanocrystal nucleation processes in materials have been recorded. Researchers used ultrashort laser pulses to rapidly heat a material, ultimately causing melting and vaporization. Application of synchronous femtosecond x-ray probe pulses are used as a stroboscopic probe to observe ultrafast atomic and molecular motions. The images provide new insight into the steps accompanying disordering, melting and refreezing, which is required to model, predict, and enhance a material's performance at extreme conditions.
- *Tuning a crystal for coherence.* Terahertz (THz) imaging and sensing can reveal depth and detail that other techniques cannot, and because terahertz radiation is non-ionizing it does not cause damage like x-rays can. While terahertz radiation is all around us in nature, it has been difficult to produce in a lab because it falls between the capabilities of electronic devices and lasers. By clever use of the inherent internal structure of a high-temperature superconducting material coupled with a special crystal geometry a new source of coherent radiation at THz frequencies has been developed. Researchers found that by using the edges of the crystal to create a resonating cavity, similar to the

mechanism for generating lasers, the switching of hundreds of naturally occurring nanoscale electronic circuits in the material (called Josephson junctions) could be synchronized. This synchronized switching emits powerful, coherent radiation in the THz frequency. In this discovery, the emitted power is proportional to the height of the crystal, and the frequency may be controlled by the width of the crystal. This new approach generates a power density several orders of magnitude greater than other methods, with the added benefit that the radiation is coherent and tunable.

- *Bringing quantum computing closer to reality.* Moore's law has been successfully used to predict the evolutionary increase in computing power enabled over the last twenty years by chip manufacturers' continual success at packing ever more transistors on a single chip. It also predicts the imminent finite end to what can be achieved using semiconductor-based logic—the limit when an individual component is only a handful of atoms. A promising path to extending computing power is a revolutionary approach based on the use of quantum bits (qubits) to store and manipulate information. Conventional computing represents information as a sequence of binary bits ("0" or "1"); in contrast, quantum computing represents information in quantum mechanical objects (qubits) that have the ability to exist in what is called a "superposition" of binary states; in essence, they can be "0" and "1" simultaneously. Superposition and other counter-intuitive properties of quantum mechanical objects enable certain classes of problems to be solved at a much higher speed on quantum computers. However, qubits are typically highly susceptible to environmental disturbance; to enhance their robustness solid-state qubits are typically utilized at ultra low temperatures. Recent studies have pushed back this boundary by showing that specific complexes in diamond, where a nitrogen impurity atom is linked to a vacant lattice site, can serve as reliable and robust qubits even at room temperature. Research showed that these specific qubits in diamond can be controlled with magnetic fields, allowing them to be isolated and manipulated to study how they fail. Understanding these failures may prove essential for the design and manipulation of much larger, interacting qubit systems required for practical quantum computing devices.
- *Nanoscience leads to breakthrough in efficiency of thermoelectric conversion*. Demonstrating the power of engineering materials at the nanoscale, researchers have achieved a 50-fold improvement in the ability of ordinary silicon to convert heat into electricity and vice versa. The family of materials capable of such conversion, named thermoelectrics, has been the focus of intense research because of their potential use in power generation and refrigeration. Until now useful thermoelectric properties only existed in a few rare materials, making the wide-scale deployment of this technology unfeasible. It was recently discovered that the shape of the silicon, fabricated in a very thin wire form, is key to attaining improved properties. As the wire diameter decreased to a few tens of nanometers, the thermoelectric properties unexpectedly improved to a level only seen in the best-known thermoelectric materials. This efficiency improvement in such an abundant and well-studied material such as silicon increases the potential to greatly expand the range of applications for thermoelectrics.

## Detailed Justification

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| **Materials Sciences and Engineering Research** | **234,429** | **332,833** | **371,190** |
| ▪ **Experimental Condensed Matter Physics** | **40,628** | **46,398** | **51,387** |

This activity supports experimental condensed matter physics emphasizing the relationship between the electronic structure and the properties of complex materials, often at the nanoscale. The focus is on systems whose behavior derives from strong correlation effects of electrons as manifested in superconducting, semi-conducting, magnetic, thermoelectric, and optical properties. Also supported is the development of new techniques and instruments for characterizing the electronic states and properties of materials under extreme conditions, such as in ultra low temperatures (millikelvin), in ultra high magnetic fields (100 Tesla), and at ultrafast time scales (femtosecond). Capital equipment is provided for scanning tunneling microscopes, electron detectors, superconducting magnets, and physical properties measurement instruments.

Improving the understanding of the electronic behavior of materials on the atomistic scale is relevant to the DOE mission, as these structures offer enhanced properties and could lead to dramatic improvements in energy generation, delivery, use, and conversion technologies. Specifically, research efforts in understanding the fundamental mechanisms in superconductivity, the elementary energy conversion steps in photovoltaics, and the energetics of hydrogen storage provide the major scientific underpinnings for the respective energy technologies. This activity also supports basic research in semiconductor and spin-based electronics of interest for the next generation information technology and electronics industries.

In FY 2010, funding will be provided for research in the area of complex and emergent behavior. The research activities will emphasize investigations on emergent behaviors arising from the collective, cooperative behavior of individual components of a system which lead to physical phenomena as diverse as phase transitions, high temperature superconductivity, colossal magnetoresistance, random field magnets, and spin liquids and glasses. These phenomena are expected to have a wide range of impact on energy relevant technologies.

Funds are also provided in FY 2010 to cover pension payments for Oak Ridge National Laboratory (including Wackenhut) and Lawrence Berkeley National Laboratory.

| | | | |
|---|---|---|---|
| ▪ **Theoretical Condensed Matter Physics** | **27,255** | **29,448** | **30,455** |

This activity supports theoretical condensed matter physics with emphasis on the theory, modeling, and simulation of electronic correlations. A major thrust is nanoscale science, where links between the electronic, optical, mechanical, and magnetic properties of nanostructures and their size, shape, topology, and composition are poorly understood. Other major research areas include strongly correlated electron systems, quantum transport, superconductivity, magnetism, and optics. Development of theory targeted at aiding experimental technique design and interpretation of experimental results is also emphasized. This activity supports the Computational Materials Science Network, which forms collaborating teams from diverse disciplines to address the increasing complexity of many current research issues. The activity also supports large-scale computation to perform complex calculations dictated by fundamental theory or to perform complex system

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |

simulations with joint funding from the Advanced Scientific Computing Research program. Capital equipment funding will be provided for items such as computer workstations and clusters.

This activity provides the fundamental knowledge for predicting the reliability and lifetime of energy use and conversion approaches and develops opportunities for next generation energy technology. Specific examples include inverse design of compound semiconductors for unprecedented solar photovoltaic conversion efficiency, solid-state approaches to improving capacity and kinetics of hydrogen storage, and ion transport mechanisms for fuel cell applications.

In FY 2010, this activity will support multi-investigator projects in theory and modeling and simulation. The research will be focused on understanding the nature and origin of highly correlated states in strongly interacting systems that have spin, charge, lattice, and orbital degrees of freedom and that are often intrinsically inhomogeneous on nanometer length scales. Research will include both theoretical and computational approaches capable of interrogating systems to gain direct insight on the mechanisms that lead to cooperative behavior.

| | | | |
|---|---|---|---|
| ▪ **Mechanical Behavior and Radiation Effects** | **13,268** | **14,336** | **14,826** |

This activity supports basic research to understand defects in materials and their effects on the load-bearing properties of strength, structure, deformation, and failure. Defect formation, growth, migration, and propagation are examined by coordinated experimental and modeling efforts over a wide range of spatial and temporal scales. Topics include deformation of ultra-fine scale materials, radiation-resistant material fundamentals, and intelligent microstructural design for increased strength, formability, and fracture resistance. The goals are to develop predictive models for the design of materials having superior mechanical properties and radiation resistance. Capital equipment funding is provided for high temperature furnaces, nanoscale mechanical property measurement tools, and ion-beam processing instrumentation.

The ability to predict materials performance and reliability and to address service life extension issues is important to the DOE mission areas of fossil, fusion, and nuclear energy conversion; radioactive waste storage; environmental cleanup; and defense. Among the key materials performance goals for these technologies are good load-bearing capacity, failure and fatigue resistance, fracture toughness and impact resistance, high-temperature strength and dimensional stability, ductility and deformability, and radiation tolerance. Since materials from large-scale nuclear reactor components to nanoscale electronic switches undergo mechanical stress and are subjected to ionizing radiation, this activity provides the fundamental scientific underpinning to enable the advancement of high-efficiency and safe energy generation, use, and storage as well as transportation systems.

In FY 2010, this activity will support research on the properties of materials in extreme environments such as the exposure to an energetic flux, chemical reactive stimulants, high temperature and pressure as well as high magnetic and electric fields. The primary emphasis will be on discovering novel phenomena and materials for improved performance with superior functionality and to establish unified models to predict the mechanical and degradation behavior of solids over multiple length and time scales. In situ experiments will be closely integrated with theoretical/computational efforts to develop a fundamental understanding of degradation mechanisms and kinetics over multiple scales from atomistic to micron and nanosecond to decades.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| ▪ **Physical Behavior of Materials** | **28,226** | **30,498** | **31,541** |

This activity supports basic research on the behavior of materials in response to external stimuli, such as temperature, electromagnetic fields, chemical environments, and the proximity effects of surfaces and interfaces. Emphasis is on the relationships between performance (such as electrical, magnetic, optical, electrochemical, and thermal performance) and the microstructure and defects in the material. Included within the activity are research in aqueous, galvanic, and high-temperature gaseous corrosion and their mitigation; the relationship of crystal defects to semiconducting, superconducting, and magnetic properties; phase equilibria and kinetics of reactions in materials in hostile environments; and diffusion and transport phenomena. Basic research is also supported to develop new instrumentation, including *in situ* experimental tools, and to probe the physical behavior in real environments encountered in energy applications. Capital equipment funding is provided for items such as physical property measurement tools that include spectroscopic and analytical instruments for chemical and electrochemical analysis.

The research supported by this activity is necessary for improving materials reliability in chemical, electrical, and electrochemical applications and for improving the ability to generate and store energy in materials. Materials in energy-relevant environments are increasingly being exposed to extreme temperatures, strong magnetic fields, and hostile chemical conditions. A detailed understanding of how materials behavior is linked to the surroundings and treatment history is critical to our understanding of corrosion, photovoltaics, fast-ion conducting electrolytes for batteries and fuel cells, novel magnetic materials for low magnetic loss power generation, magnetocaloric materials for high-efficiency refrigeration, and new materials for high-temperature gasification.

In FY 2010, this activity will support research on energy conversion designed to achieve low cost power conversion. The research will include the search for photoconversion materials, such as polycrystalline, nanocrystalline, and organic materials to replace expensive single crystals; innovative design of interpenetrating photoconversion materials networks to improve charge separation and collection efficiency; and the development of novel processes to obtain extremely high conversion efficiencies.

| | | | |
|---|---|---|---|
| ▪ **Neutron and X-ray Scattering** | **31,811** | **46,971** | **48,613** |

This activity supports basic research on the fundamental interactions of photons and neutrons with matter to achieve an understanding of the atomic, electronic, and magnetic structures and excitations of materials and the relationships of these structures and excitations to materials properties. The main emphasis is on x-ray and neutron scattering, spectroscopy, and imaging research, primarily at major BES-supported user facilities. The development and improvement of next-generation instrumentation, novel detectors, sample environments, data analysis, tools, and technology for producing polarized neutrons, are key aspects of this activity. Instrumentation development and experimental research in ultrafast materials science, including research aimed at generating, manipulating, and detecting ultrashort and ultrahigh-peak-power electron, x-ray, and laser pulses to study ultrafast physical phenomena in materials, is an integral part of the portfolio. Capital equipment funding is provided for items such as detectors, monochromators, focusing mirrors, and beamline instrumentation at the facilities.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |

The increasing complexity of DOE mission-relevant materials such as superconductors, semiconductors, and magnets requires ever more sophisticated scattering techniques to extract useful knowledge and to develop new theories for the behavior of these materials. X-ray and neutron scattering probes are some of the primary tools for characterizing the atomic, electronic, and magnetic structures of materials. Additionally, neutrons play a key role in hydrogen research as they provide atomic- and molecular-level information on structure, diffusion, and interatomic interactions for hydrogen. They also allow access to the morphologies that govern useful properties in catalysts, membranes, proton conductors, and hydrogen storage materials. The activity is relevant to the behavior of matter in extreme environments, especially at high pressure.

In FY 2010, scattering research will take advantage of increased neutron and x-ray fluxes and optimized beamline optics at BES user facilities, combined with specialized instrumentation, to investigate electrochemical processes in real time. Emphasis will be on using elastic and inelastic neutron scattering to determine structure and local dynamics and on neutron reflectivity to examine electrode/electrolyte interfaces. Time-resolved measurements will be used to study phase transformation kinetics in both amorphous and crystalline phases. The new capabilities will be used to study materials under ultrahigh pressure and to identify novel phase and phenomena not accessible via ambient conditions. Ultrafast materials science research will take advantage of new x-ray and neutron sources to perform research designed to understand the physics of strongly correlated systems, such as high temperature superconductors and magnetic materials with colossal magnetoresistance.

| | | | |
|---|---|---|---|
| ▪ **Electron and Scanning Probe Microscopies** | **16,635** | **20,474** | **21,174** |

This activity supports basic research in condensed matter physics and materials physics using electron scattering and microscopy and scanning probe techniques. The research includes experiments and theory to understand the atomic, electronic, and magnetic structures of materials. This activity also supports the development and improvement of electron scattering and scanning probe instrumentation and techniques, including ultrafast diffraction and imaging techniques. Capital equipment funding is provided for items such as new scanning probes and electron microscopes as well as ancillary equipment including high resolution detectors.

Performance improvements for environmentally acceptable energy generation, transmission, storage, and conversion technologies likewise depend on a detailed understanding of the structural characteristics of advanced materials. Electron and scanning probe microscopies are some of the primary tools for characterizing the atomic, electronic, and magnetic structures of materials. The activity is relevant to hydrogen research through the structural determination of nanostructured materials for hydrogen storage and solar hydrogen generation.

In FY 2010, research will emphasize the development of tools that will dramatically improve spatial, time, and energy resolution to provide fundamental understanding of the electron and charge transfer processes and mechanisms by which ions interact with electrode materials. The effort will focus studies of transient non-equilibrium nanoscale structures, including adsorbed species in both vacuum and electrochemical environments, with near-atomic spatial resolution and femtosecond time scale. Ultrafast electron scattering will be developed as a companion tool to ultrafast photon probes.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| | (dollars in thousands) | | |
| ▪ **Experimental Program to Stimulate Competitive Research (EPSCoR)** | **14,680** | **16,755** | **8,520** |

This activity supports basic research spanning the broad range of science and technology programs at DOE in states that have historically received relatively less Federal research funding. The EPSCoR states are shown in the table below. The research supported by EPSCoR includes materials sciences, chemical sciences, physics, energy-relevant biological sciences, geological and environmental sciences, high energy physics, nuclear physics, fusion energy sciences, advanced computing, and the basic sciences underpinning fossil energy and energy efficiency and renewable energy.

The core activity interfaces with all other core activities within the Office of Science. It is also responsive and supports the DOE mission in the areas of energy and national security and in mitigating their associated environmental impacts.

In FY 2010, support will continue for basic research related to all DOE mission areas and to enhance collaborative efforts with DOE user facilities. The FY 2010 request, after subtracting the additional funding provided by Congress in FY 2009, provides a funding increase for EPSCoR at a rate equivalent to increases for BES core research as a whole. Activities initiated with the additional funding provided by Congress in FY 2009 include additional implementation awards and research partnership awards. These activities are funded, to the extent possible, through their completion in FY 2011.

The following table shows EPSCoR distribution of funds by state.

**EPSCoR Distribution of Funds by State**

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| Alabama | 1,074 | 135 | — |
| Alaska | 309 | — | — |
| Arkansas | — | — | — |
| Delaware | 980 | 980 | — |
| Hawaii | — | — | — |
| Idaho | 400 | 400 | — |
| Iowa[a] | — | — | — |
| Kansas | 405 | — | — |
| Kentucky | — | 650 | 700 |
| Louisiana | 522 | 440 | 300 |
| Maine | 650 | 650 | — |
| Mississippi | — | — | — |

[a] Became eligible in FY 2009.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Montana | 531 | 350 | 450 |
| Nebraska | 784 | — | — |
| Nevada | 468 | — | — |
| New Hampshire | 545 | 569 | — |
| New Mexico | 1,455 | — | 750 |
| North Dakota | 450 | — | — |
| Oklahoma | 761 | 681 | — |
| Puerto Rico | 400 | 350 | 450 |
| Rhode Island | — | — | — |
| South Carolina | 1,315 | 785 | — |
| South Dakota | 405 | — | — |
| Tennessee | 1,821 | 135 | 314 |
| U.S. Virgin Islands | — | — | — |
| Utah[a] | — | — | — |
| Vermont | — | — | — |
| West Virginia | 1,318 | — | — |
| Wyoming | — | — | — |
| Technical Support | 87 | 250 | 250 |
| Other[b] | — | 10,380 | 5,306 |

- **Synthesis and Processing Science** **15,587** **16,841** **17,417**

This activity supports basic research to develop new techniques to synthesize new materials with desired structure, properties, or behavior; to understand the physical phenomena that underpin materials synthesis such as diffusion, nucleation, and phase transitions; and to develop *in situ* monitoring and diagnostic capabilities. The emphasis is on the synthesis of complex thin films and nanoscale objects with atomic layer-by-layer control; preparation techniques for pristine single crystal and bulk materials with novel physical properties; understanding the contributions of the liquid and other precursor states to the processing of bulk nanoscale materials; and low energy processing techniques for large scale nanostructured materials. The focus on bulk synthesis and crystal and thin films growth via physical means is complementary to the Materials Chemistry and Biomolecular Materials activity, which emphasizes chemical and biomimetic routes to new materials synthesis and design. This activity includes operation of the Materials Preparation Center at the

[a] Became eligible in FY 2009.
[b] Uncommitted funds in FY 2009 and FY 2010 will be competed among all EPSCoR states.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |

Ames Laboratory, which develops innovative and superior processes for materials preparation and provides small quantities of research-grade, controlled-purity materials and crystals not otherwise available to academic, governmental, and industrial research communities to be used for research purposes. Capital equipment funding is provided for crystal growth apparatus, heat treatment furnaces, lasers, chemical vapor and molecular beam epitaxial processing equipment, plasma and ion sources, and deposition instruments.

Synthesis and processing science is a key component in the discovery and design of a wide variety of energy relevant materials. In this regard, the activity supports the DOE's mission in the synthesis of wide bandgap semiconductors for solid state lighting; light-weight metallic alloys for efficient transportation; novel materials such as metal organic frameworks for hydrogen storage; and structural ceramics and the processing of high temperature superconductors for near zero-loss electricity transmission. The research activity aims at providing synthesis and processing capabilities to enable the manipulation of individual spin, charge, and atomic configurations in ways to probe the atomistic basis for materials properties.

In FY 2010, research will seek to develop novel design rules for synthesizing nanostructured materials and assemblies for energy relevant systems. Research on advanced materials for electrical energy storage will include studies on the fundamental electrochemical characteristics of the nanoscale building blocks with varying size and shape and in confined geometry.

| | | | |
|---|---|---|---|
| ▪ **Materials Chemistry and Biomolecular Materials** | **46,339** | **51,569** | **53,333** |

This activity supports basic research in chemical and bio-inspired synthesis and discovery of new materials. In the materials chemistry area, discovery, design, and synthesis of novel materials with an emphasis on the chemistry and chemical control of structure and collective properties are supported. Major thrust areas include nanoscale chemical synthesis and assembly; solid state chemistry for controlled synthesis and tailored reactivities; novel polymeric materials; surface and interfacial chemistry including electrochemistry; and the development of new, science-driven, laboratory-based analytical tools and techniques. In the biomolecular materials area, research supported includes biomimetic and bioinspired functional materials and complex structures, and materials aspects of energy conversion processes based on principles and concepts of biology. The focus on exploratory chemical and biomolecular formation of new materials is complementary to the emphasis on bulk synthesis, crystal growth, and thin films in the Synthesis and Processing Science activity. Capital equipment funding is provided for items such as advanced nuclear magnetic resonance and magnetic resonance imaging instruments and novel atomic force microscopes.

Research supported in this activity underpins many energy-related technological areas such as batteries and fuel cells, catalysis, energy conversion and storage, friction and lubrication, high-efficiency electronic devices, hydrogen generation and storage, light-emitting materials, light-weight high-strength materials, and membranes for advanced separations.

In FY 2010, basic research will be performed on the design and synthesis of new energy relevant materials and processes which include new three-dimensional nanostructured architectures that can be precisely tailored for batteries and ultracapacitors. Emphasis will be on developing a predictive understanding of the role of interfaces in the electrochemical processes underpinning energy storage technologies, devising experimental strategies for atom-by-atom synthesis or molecular assembly of

(dollars in thousands)

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|

structures for new storage materials, and exploring novel concepts for electrical and electrochemical energy storage. The research will seek to advance the ability for materials to self-repair, regulate, clean, sequester impurities, and tolerate abuse which will ultimately improve their performance. Nanoscale hybrid materials and advances in the understanding of nature's design of photosynthetic and catalytic systems will be used to study inorganic/organic components in engineered assemblies to produce new materials for the conversion of solar photons to fuels and chemicals.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **Energy Frontier Research Centers (EFRCs)[a]** | **—** | **55,300** | **55,300** |

This activity supports those EFRCs with an emphasis on Materials Sciences and Engineering that are coordinated with the ongoing core research activities within the subprogram. EFRCs are multi-investigator and multi-disciplinary collaborations that foster, encourage, and accelerate basic research to provide the basis for transformative energy technologies of the future. The EFRC program represents an important implementation of the BES strategic plan for grand challenge and use-inspired energy science that has been set forth in the series of BESAC and Basic Research Needs workshops over the last six years[b]. The scientific challenges emerging from these studies describe a new era of science—an era in which materials functionalities are designed to specifications and chemical transformations are manipulated at will. The EFRCs were established in FY 2009 through a competitive Funding Opportunity Announcement that was open to universities, DOE laboratories, for-profit companies, and nonprofit entities. EFRCs bring together the skills and talents of a critical mass of investigators to enable energy relevant, basic research of a scope and complexity that would not be possible with the standard single-investigator or small-group award and thus complement the ongoing BES core research activities. The EFRCs inspire, train, and support leading scientists of the future who will ultimately be called upon to solve the nation's energy challenges in the 21st century.

While EFRCs are inherently multi-disciplinary in nature, this activity includes EFRCs that are focused on the design, discovery, synthesis, and characterization of new materials for improved conversion of solar energy into electricity; that store electrical energy in innovative new ways with greatly increased capacity; that are resistant to corrosion, decay, or failure in extreme conditions of temperature, pressure, radiation, or chemical exposures; that take advantage of emergent phenomena, such as superconductivity, to improve energy transmission; and that optimize and control photon management in solid state materials to improve energy efficiency. The Centers will enhance our fundamental understanding of complex materials by combining experimental research with theory, computation and advanced simulations. Unifying themes in the research include the synthesis and characterization of materials and phenomena on the nanometer length scale and ultrafast (femtoseconds to attoseconds) timescales. Observing the dynamics of energy flow in theses systems is necessary if we are to learn to control their behavior.

In FY 2010, emphasis will be placed on ensuring that the EFRCs established late in FY 2009 are progressing toward their full collaborative and scientific potential using management protocols develop for other large-scale activities.

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[a] A complimentary set of EFRCs is also supported in the Chemical Sciences, Geosciences, and Energy Biosciences subprogram.

[b] http://www.sc.doe.gov/bes/reports/list.html

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| ▪ **Energy Innovation Hub – Batteries and Energy Storage** | **—** | **—** | **34,020** |

As an energy carrier, electricity has no rival with regard to its environmental cleanliness, flexibility in interfacing with multiple production sources and end uses, and efficiency of delivery. Electrical energy storage offers one of the most significant solutions to the effective use of electricity in energy management. Improved energy storage is critical for load-leveling and peak-shaving for more efficient and reliable smart electric grid technologies; plug-in hybrid or all-electric vehicles in the transportation sector vehicles; and the deployment of intermittent renewable energy power sources such as solar, wind, and wave energy into the utility sector. Today's electrical energy storage approaches, such as batteries and electrochemical devices, suffer from limited energy and power capacities, lower-than-desired rates of charge and discharge, calendar and cycle life limitations, low abuse tolerance, high cost, and poor performance at high or low temperatures. These performance deficiencies adversely affected the successful use and integration of renewable, intermittent power sources such as solar, wind, and wave energy into the utility sector. These same fundamental problems have also limited broad consumer acceptance and market adaptation of hybrid and all-electric vehicles.

Recent developments in nanoscience and nanotechnology offer tantalizing clues on promising scientific directions that may enable conceptual breakthroughs. They include the abilities to synthesize novel nanoscale materials with architectures tailored for specific electrochemical performance, to characterize materials and dynamic chemical processes at the atomic and molecular level, and to simulate and predict structural and functional relationships using modern computational tools. Based on this, radically new concepts in materials design can be developed for producing storage devices with materials that are abundant and low in manufacturing cost, are capable of storing higher energy densities, have long cycle lifetimes, and have high safety and abuse tolerance. Together, these new capabilities provide the potential for addressing the gaps in cost and performance separating the current electrical energy storage technologies and those required for sustainable utility and transportation needs.

In FY 2010, research will be included in the following areas. Fundamental performance limitations of energy storage systems are rooted in the constituent materials making up an electrical energy storage device, and novel approaches are needed to develop multifunctional electrical energy storage materials that offer new self-healing, self-regulating, failure-tolerant, impurity-sequestering, and sustainable characteristics. The Hub would address a number of specific areas of research for both batteries and electrochemical capacitors that have been identified in the BES workshop report *Basic Research Needs for Electrical Energy Storage*. These include:

- Efficacy of structure in energy storage—new approaches combining theory and synthesis for the design and optimization of materials architectures including self-healing, self-regulation, failure-tolerance, and impurity sequestration.
- Charge transfer and transport—molecular scale understanding of interfacial electron transfer. Electrolytes—electrolytes with strong ionic solvation, yet weak ion-ion interactions, high fluidity, and controlled reactivity.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |

- Probes of energy storage chemistry and physics at all time and length scales—analytical tools capable of monitoring changes in structure and composition at interfaces and in bulk phases with spatial resolution from atomic to mesoscopic levels and temporal resolution down to femtoseconds.
- Multi-scale modeling—computational tools with improved integration of length and time scales to understand the complex physical and chemical processes that occur in electrical energy storage processes from the molecular to system scales.

One-time funding of $10,000,000 will be provided for Hub start-up needs, excluding any new construction.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **General Plant Projects (GPP)** | **—** | **4,243** | **4,604** |

GPP funding is provided for minor new construction, for other capital alterations and additions, and responsibilities to land, buildings, and utility systems as part of the BES stewardship responsibilities. Funding of this type is essential for maintaining the productivity and usefulness of the Department-owned facilities and in meeting requirements for safe and reliable facilities operation. Additional GPP is included in the Chemical Sciences, Geosciences, and Energy Biosciences subprogram and the Scientific User Facilities subprogram. The total estimated cost of each GPP project will not exceed $10,000,000.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **SBIR/STTR** | **—** | **8,831** | **9,922** |

In FY 2008, $5,800,000 and $696,000 were transferred to the SBIR and STTR programs, respectively. The FY 2009 and FY 2010 amounts shown are the estimated requirements for the continuation of the congressionally mandated SBIR and STTR program.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **Total, Materials Sciences and Engineering** | **234,429** | **341,664** | **381,112** |

## Explanation of Funding Changes

| | FY 2010 vs. FY 2009 ($000) |
|---|---|

### Materials Sciences and Engineering Research

- **Experimental Condensed Matter Physics**

  Increased funding is provided for enhanced research in the area of complex and emergent behavior ($+1,587,000).

  Funding is provided to cover pension payments for ORNL (including Wackenhut) and LBNL ($+3,402,000). — $+4,989

- **Theoretical Condensed Matter Physics**

  Increased funding is provided for enhanced research to support multi-investigator projects in theory and modeling and simulation. — +1,007

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| ▪ **Mechanical Behavior and Radiation Effects** | |
| Increased funding is provided for enhanced research on the properties of materials in extreme environments such as the exposure to an energetic flux, chemical reactive stimulants, high temperature and pressure, and high magnetic and electric fields. | +490 |
| ▪ **Physical Behavior of Materials** | |
| Increased funding is provided for enhanced research on energy conversion designed to achieve low cost power conversion. | +1,043 |
| ▪ **Neutron and X-ray Scattering** | |
| Increased funding is provided for scattering research to take advantage of increased neutron and x-ray fluxes and optimized beamline optics at BES user facilities, combined with specialized instruments, to investigate electrochemical processes in real time. | +1,642 |
| ▪ **Electron and Scanning Probe Microscopies** | |
| Increased funding is provided to emphasize the development of tools that will dramatically improve spatial, time, and energy resolution to provide fundamental understanding of the electron and charge transfer processes and mechanisms by which ions interact with electrode materials. | +700 |
| ▪ **Experimental Program to Stimulate Competitive Research (EPSCoR)** | |
| The FY 2010 request accounts for the additional funding provided by Congress in FY 2009 ($-8,515,000), and provides a funding increase for EPSCoR at the same rate as BES core research ($+280,000). Additional funds provided in FY 2009 were used, to the extent possible, to fully fund grants and minimize outyear mortgages. | -8,235 |
| ▪ **Synthesis and Processing Science** | |
| Increased funding is provided to develop novel design rules for synthesizing nanostructured materials and assemblies for energy relevant systems. | +576 |
| ▪ **Materials Chemistry and Biomolecular Materials** | |
| Increased funding is provided for research on the design and synthesis of new energy relevant materials and processes which includes new three-dimensional nanostructured architectures that can be precisely tailored for batteries and ultracapacitors. | +1,764 |
| ▪ **Energy Innovation Hub – Batteries and Energy Storage** | |
| Funds are provided for an Energy Innovation Hub focused on developing radically new concepts in materials design for producing storage devices with materials that are abundant and low in manufacturing cost, are capable of storing higher energy densities, have long cycle lifetimes, and have safety and abuse tolerance. | +34,020 |

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| ▪ **General Plant Projects (GPP)** | |
| Increased funding is provided for GPP. | +361 |
| **Total, Materials Sciences and Engineering Research** | **+38,357** |
| **SBIR/STTR** | |
| Increased funding in SBIR/STTR funding because of an increase in total operating expense. | +1,091 |
| **Total Funding Change, Materials Sciences and Engineering** | **+39,448** |

## Chemical Sciences, Geosciences, and Energy Biosciences

## Funding Schedule by Activity

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Chemical Sciences, Geosciences, and Energy Biosciences | | | |
| Chemical Sciences, Geosciences, and Energy Biosciences Research | 216,747 | 285,061 | 329,289 |
| SBIR/STTR | — | 7,809 | 9,068 |
| Total, Chemical Sciences, Geosciences, and Energy Biosciences | 216,747 | 292,870 | 338,357 |

### Description

This subprogram supports experimental, theoretical, and computational research to provide fundamental understanding of chemical transformations and energy flow in systems relevant to DOE missions. This knowledge serves as a basis for the development of new processes for the generation, storage, and use of energy and for mitigation of the environmental impacts of energy use.

In fundamental interactions, basic research is supported in atomic, molecular, and optical sciences; gas-phase chemical physics; ultrafast chemical science; theoretical and computational chemistry; and condensed phase and interfacial molecular science. Emphasis is placed on structural and dynamical studies of atoms, molecules, and nanostructures, and the description of their interactions in full quantum detail, with the aim of providing a complete understanding of reactive chemistry in the gas phase, condensed phase, and at interfaces. Novel sources of photons, electrons, and ions are used to probe and control atomic, molecular, and nanoscale matter. Ultrafast optical and x-ray techniques are developed and used to study chemical dynamics. There is a focus on cooperative phenomena in complex chemical systems, such as the effect of solvation on chemical structure, reactivity, and transport and the coupling of complex gas-phase chemistry with turbulent flow in combustion.

In photochemistry and biochemistry, including solar photochemistry, photosynthetic systems, and physical biosciences, research is supported on the molecular mechanisms involved in the capture of light energy and its conversion into chemical and electrical energy through biological and chemical pathways. Natural photosynthetic systems are studied to create robust artificial and bio-hybrid systems that exhibit the biological traits of self assembly, regulation, and self repair. Complementary research encompasses organic and inorganic photochemistry, photo-induced electron and energy transfer, photo-electrochemistry, and molecular assemblies for artificial photosynthesis. Inorganic and organic photochemical studies provide information on new chromophores, donor-acceptor complexes, and multi-electron photocatalytic cycles. Photoelectrochemical conversion is explored in studies of nanostructured semiconductors. Biological energy transduction systems are investigated, with an emphasis on the coupling of plant development and microbial biochemistry with the experimental and computational tools of the physical sciences.

In chemical transformations, research themes include the characterization, control, and optimization of chemical transformations, including efforts in catalysis science; separations and analytical science; actinide chemistry; and geosciences. Catalysis science underpins the design of new catalytic methods for the clean and efficient production of fuels and chemicals and emphasizes inorganic and organic complexes; interfacial chemistry; nanostructured and supramolecular catalysts; photocatalysis and electrochemistry; and bio-inspired catalytic processes. Heavy element chemistry focuses on the spectroscopy, bonding, and reactivity of actinides and fission products. Complementary research on chemical separations focuses on the use of nanoscale membranes and the development of novel metal-adduct complexes. Chemical analysis research emphasizes laser-based and ionization techniques for molecular detection, particularly the development of chemical imaging techniques. Geosciences research covers analytical and physical geochemistry, rock-fluid interactions, and flow/transport phenomena. This research provides a fundamental basis for understanding the environmental contaminant fate and transport and for predicting the performance of repositories for radioactive waste or carbon dioxide ($CO_{2)}$ sequestration.

The proposed Energy Innovation Hub focused on Fuels from Sunlight will consist of multidisciplinary teams of experts that blend basic scientific research with technology development, engineering design, and energy policy. They will bridge the gap between basic scientific breakthroughs and industrial commercialization through proof-of-concept prototyping, modeling, measurement, and verification of the potential for major impacts.

**Selected FY 2008 Research Accomplishments**

- *Ultrafast snapshots of molecular dynamics.* New ultrafast laser techniques are allowing scientists to follow the concerted motion of the electrons and atoms that comprise a molecule as it undergoes chemical change. Distortions in the electron cloud that holds a molecule together can occur in less than one femtosecond, or one quadrillionth of a second. High harmonic generation (HHG) is a technique in which the intense, oscillating field from an ultrafast laser pulse first rips away an electron from a molecule and then slams it back into the ionic core of the molecule, generating soft x-ray photons. In recent studies of dinitrogen tetraoxide ($N_2O_4$), researchers first excited vibrational motion in the molecule with an optical ultrafast laser pulse and then used a second ultrafast pulse to produce soft x-rays from the vibrating molecule. HHG is highly sensitive to the nature of the molecular orbitals from which the electron is plucked and those orbitals (the electron cloud) are sensitive to the shape of the molecule. Thus, HHG could monitor the evolution of the molecular orbitals of $N_2O_4$ as it vibrated. This exciting result opens the door to future studies of the concerted motion of electrons and atoms in molecules that probe a foundational tenet of chemistry—that the rapid motion of electrons is separable from the slower motion of atoms in a molecule undergoing chemical change.
- *A molecular-scale understanding of carbon separation in advanced media.* Long-term solutions to global climate change require effective media to first separate $CO_2$ from pre- or post-combustion processes. Currently, this separation is done with amine-based solution chemistry, which is both expensive and requires large amounts of hazardous chemicals. New research aimed at finding molecular solids for this task has focused on calixarenes, which are a class of large molecules that form cage-like structures into which smaller molecules can enter and be retained. They feature an absorption selectivity that is a critical criterion for the separation of $CO_2$ from other components in process streams. The molecular solid of the calixarene p-tert-butylcalix[4]arene (TBC4) is a prototypical example of a compound that might be used in such a system. The motion of the guest molecules $CO_2$ and $CH_4$ were studied in TBC4 over a range of temperatures using molecular simulation technique. The results show key differences in the rattling motion and free energy of absorption for $CO_2$ and $CH_4$ and provide fundamental data for optimization of these molecular solids as $CO_2$ separation media.
- *Chemical imaging for solar photochemistry*. Chemical imaging is used to describe experimental methods in which chemical processes are imaged with both molecular specificity and high spatial resolution. A recent advance in confocal microscopy makes it possible to simultaneously spatially resolve the reaction of a single molecule and to measure the rate of that reaction with ultrafast time

resolution, thus adding temporal capability to chemical imaging. This new microscopy was used to measure rates of light-induced electron exchange between molecules and single semiconductor nanoparticles. Photo-induced electron transfer was studied at a single location on a semiconductor surface before the excited molecule had dissipated its thermal energy through molecular vibration. The new technique also allowed the migration of excitation on a nanoparticle to be visualized during an electron-transfer reaction that is of fundamental importance in converting sunlight into electricity. This creative redesign of confocal microscopy is simple and amenable to existing confocal microscopes, an important advance in the field of chemical imaging.

- *New catalysts from cheap and abundant metals*. The processing of petroleum into fuels and chemicals currently relies heavily on precious and scarce noble-metal catalysts because of their selectivity and activity. Sustainable catalytic conversion of biomass feedstocks into fuels requires the design and development of novel catalysts based on cheap and abundant metals. Research results from the fields of organometallic, bio-inspired, and solid-state chemistry are converging on a new set of catalysts based on common metals such as iron, zinc, nickel, copper, and manganese. With the aid of computational chemistry, new materials have been designed with tailored catalytic properties. Examples include a bio-inspired iron-oxo complex that selectively converts methane to methanol with much higher yields than natural enzymes and new alloys of zinc-nickel that are more active and selective in the conversion of acetylene to ethylene than classical palladium-silver alloys.
- *Minerals as semiconductors.* The semiconducting properties of a wide range of minerals are often ignored in the study of their geochemical behavior. Experiments on natural hematite ($Fe_2O_3$) have conclusively demonstrated that interfacial electron transfer reactions at one surface of a crystal in an electrolytic solution couple with those at another surface. This causes one crystal face to dissolve while other faces grow and creates gradients in the electrical potential within the crystal that can drive conductance from one crystal face to another. Bulk crystal conduction is likely to be a general phenomenon that occurs in a host of naturally abundant semiconducting minerals, leading to interfacial processes that are important, but previously under appreciated, in the geochemistry of soils and sediments.

## Detailed Program Justification

| (dollars in thousands) | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **Chemical Sciences, Geosciences, and Energy Biosciences Research** | **216,747** | **285,061** | **329,289** |
| ▪ **Atomic, Molecular, and Optical Science** | **18,353** | **22,886** | **23,669** |

This activity supports theory and experiments to understand structural and dynamical properties of atoms, molecules, and nanostructures. The research emphasizes the fundamental interactions of these systems with photons and electrons to characterize and control their behavior. These efforts aim to develop accurate quantum mechanical descriptions of properties and dynamical processes of atoms, molecules, and nanoscale matter. The study of energy transfer within isolated molecules provides the foundation for understanding chemical reactivity, i.e., the process of energy transfer to ultimately make and break chemical bonds. Topics include the development and application of novel, ultrafast optical probes of matter, particularly x-ray sources; the interactions of atoms and molecules with intense electromagnetic fields; and studies of collisions and many-body cooperative interactions of atomic and molecular systems, including ultracold atomic and molecular gases. Capital equipment

| | (dollars in thousands) | |
|---|---|---|
| FY 2008 | FY 2009 | FY 2010 |

funding is provided for items such as lasers and optical equipment, unique ion sources or traps, position-sensitive and solid-state detectors, control and data processing electronics, and computational resources.

The knowledge and techniques produced by this activity form a science base that underpins several aspects of the DOE mission. New methods for using photons, electrons, and ions to probe matter lead to more effective use of BES synchrotron, nanoscience, and microcharacterization facilities. Similarly, the study of formation and evolution of energized states in atoms, molecules, and nanostructures provides a fundamental basis for understanding elementary processes in solar energy conversion and radiation-induced chemistry. The activity also supports research on the fundamental interactions of atoms, molecules, and ions of importance to fusion and fission energy research.

In FY 2010, continued emphasis will be placed on the development of new ultrafast x-ray and optical probes of matter, including the first experiments to be performed on the Linac Coherent Light Source; on theoretical and computational methods for the interpretation of ultrafast measurements; and on the use of optical fields to control and manipulate quantum mechanical systems. In FY 2010, there is an increase for ultrafast science and for the control quantum systems.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **Chemical Physics Research** | **40,761** | **47,886** | **51,468** |

This activity supports experimental and theoretical investigations in the gas phase, in condensed phases, and at interfaces aimed at elucidating the chemical transformations and physical interactions that govern combustion; surface reactivity; and solute/solvent structure, reactivity, and transport. The gas-phase chemical physics portion emphasizes studies of the dynamics and rates of chemical reactions at energies characteristic of combustion and the chemical and physical properties of key combustion intermediates. The goal is development of validated theories and computational tools for predicting chemical reaction rates for use in combustion models and experimental tools for validating these models. Combustion models using this input are developed that incorporate complex chemistry with the turbulent flow and energy transport characteristics of real combustion processes. This activity includes support for the Combustion Research Facility (CRF), a multi-investigator research laboratory for the study of combustion science and technology that emphasizes experiment, theory, and computation in chemical dynamics, chemical kinetics, combustion modeling, and diagnostic development. The condensed-phase and interfacial chemical physics portion of this activity emphasizes molecular understanding of chemical, physical, and electron-driven processes in aqueous media and at interfaces. Studies of reaction dynamics at well-characterized metal or metal-oxide surfaces lead to the development of theories on the molecular origins of surface-mediated catalysis and heterogeneous chemistry. Research confronts the transition from detailed, molecular-scale understanding to cooperative and collective phenomena in complex systems. Capital equipment funding is provided for items such as lasers and optical equipment, novel position-sensitive and temporal detectors, specialized vacuum chambers for gas-phase and surface experiments, spectrometers, and computational resources.

The gas-phase portion of this activity contributes strongly to the DOE mission in the area of the efficient and clean combustion of fuels. The chemical complexity of combustion has challenged predictive modeling. Truly predictive combustion models enable the design of new combustion devices (such as internal combustion engines, burners, and turbines) with maximum energy efficiency and minimal environmental consequences. In transportation, the changing composition of

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |

fuels, from those derived from light, sweet crude oil to biofuels and fuels from alternative fossil feedstocks, puts increasing emphasis on the need for science-based design of modern engines. The condensed-phase and interfacial portion of this activity impacts a variety of mission areas by providing a fundamental basis for understanding chemical reactivity in complex systems, such as those encountered in catalysis and environmental processes. Surface-mediated chemistry research in this activity complements more directed efforts in heterogeneous catalysis. Condensed-phase and interfacial chemical physics research on dissolution, solvation, nucleation, separation, and reaction provides important fundamental knowledge relevant to the environmental contaminant transport in mineral and aqueous environments. Fundamental studies of reactive processes driven by radiolysis in condensed phases and at interfaces provide improved understanding of radiolysis effects in nuclear fuel and waste environments.

In FY 2010, there will be increased emphasis for experimental, theoretical, and computational research aimed at developing predictive models for clean and efficient combustion of biofuels and alternative fossil fuels. Elucidating the reactivity of individual molecular sites in interfacial processes and the effects of cooperative phenomena on chemical reactivity in the condensed phase will also receive emphasis. In FY 2010, there is an increase for research related to the combustion of alternative fuels, for emergent behavior in condensed phase systems, and for interfacial science relevant to electrical energy storage, including studies for electrode-electrolyte interfaces.

There is also an increase in FY 2010 to cover pension payments for Oak Ridge National Laboratory (including Wackenhut) and Lawrence Berkeley National Laboratory.

| | | | |
|---|---|---|---|
| ▪ **Solar Photochemistry** | **30,479** | **34,685** | **35,871** |

This activity supports molecular-level research on solar energy capture and conversion in the condensed phase and at interfaces. These investigations of solar photochemical energy conversion focus on the elementary steps of light absorption, electrical charge generation, and charge transport within a number of chemical systems, including those with significant nanostructured composition. Supported research areas include organic and inorganic photochemistry and photocatalysis, photoinduced electron and energy transfer in the condensed phase and across interfaces, photoelectrochemistry, and artificial assemblies for charge separation and transport that mimic natural photosynthetic systems. This activity, with its integration of physical and synthetic scientists devoted to solar photochemistry, is unique to DOE. Capital equipment funding is provided for items such as ultrafast laser systems, scanning tunneling microscopes, fast Fourier transform infrared and Raman spectrometers, and computational resources.

Solar photochemical energy conversion is an important option for generating electricity and chemical fuels and therefore plays a vital role in the DOE’s development of solar energy as a viable component of the nation’s energy supply. Photoelectrochemistry provides an alternative to semiconductor photovoltaic cells for electricity generation from sunlight using closed, renewable energy cycles. Solar photocatalysis, achieved by coupling artificial photosynthetic systems for light harvesting and charge transport with the appropriate electrochemistry, provides a direct route to the generation of fuels such as hydrogen, methane, and complex hydrocarbons. Fundamental concepts derived from studying highly efficient excited-state charge separation and transport in molecular assemblies is also applicable to future molecular optoelectronic device development.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |

In FY 2010, continued emphasis will be placed on studies of semiconductor/polymer interfaces, multiple charge generation within semiconductor nanoparticles, and dye-sensitized solar cells. In FY 2010, there is an increase for research on inorganic/organic donor-acceptor molecular assemblies and the use of nanoscale materials in solar photocatalytic generation of chemical fuels.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **Photosynthetic Systems** | **15,715** | **17,884** | **18,496** |

This activity supports fundamental research on the biological conversion of solar energy to chemically stored forms of energy. Topics of study include light harvesting, exciton transfer, charge separation, transfer of reductant to carbon dioxide, as well as the biochemistry of carbon fixation and carbon storage. Emphasized areas are those involving strong intersection between biological sciences and energy-relevant chemical sciences and physics, such as in self-assembly of nanoscale components, efficient photon capture and charge separation, predictive design of catalysts, and self-regulating/repairing systems. Capital equipment funding is provided for items such as ultrafast lasers, high-speed detectors, spectrometers, environmentally controlled chambers, high-throughput robotic systems, and computational resources.

The impact of research in this activity is to uncover the underlying structure-function relationships and to probe dynamical processes in natural photosynthetic systems to guide the development of robust artificial and bio-hybrid systems for conversion of solar energy into electricity or chemical fuels. The ultimate goal is the development of bio-hybrid systems in which the best features from nature are selectively used while the shortcomings of biology are bypassed. Achieving this goal would impact DOE’s efforts to develop solar energy as an efficient, renewable energy source.

In FY 2010, research will emphasize understanding and control of the weak intermolecular forces governing molecular assembly in photosynthetic systems; understanding the biological machinery for cofactor insertion into proteins and protein subunit assemblies; adapting combinatorial, directed-evolution, and high-throughput screening methods to enhance fuel production in photosynthetic systems; characterizing the structural and mechanistic features of new photosynthetic complexes; and determining the physical and chemical rules that underlie biological mechanisms of repair and photo-protection. In FY 2010, there is an increase for solar energy conversion, including research on biological and bio-hybrid systems and enhanced efforts in understanding defect tolerance and self-repair in natural photosynthetic systems.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **Physical Biosciences** | **15,105** | **17,189** | **17,777** |

This activity combines experimental and computational tools from the physical sciences with biochemistry and molecular biology. A fundamental understanding of the complex processes that convert and store energy in living systems is sought. Research supported includes studies that investigate the mechanisms by which energy transduction systems are assembled and maintained, the processes that regulate energy-relevant chemical reactions within the cell, the underlying biochemical and biophysical principles determining the architecture of biopolymers and the plant cell wall, and active site protein chemistry that provides a basis for highly selective and efficient bio-inspired catalysts. Capital equipment is provided for items including advanced atomic force and optical microscopes, lasers and detectors, equipment for x-ray or neutron structure determinations, and Fourier-transform infrared and nuclear magnetic resonance spectrometers.

| | (dollars in thousands) | |
|---|---|---|
| FY 2008 | FY 2009 | FY 2010 |

The research provides basic structure-function information necessary to accomplish solid-phase nanoscale synthesis in a targeted manner, i.e., controlling the basic architecture of energy-transduction and storage systems. This impacts numerous DOE interests, including improved biochemical pathways for biofuel production, next generation energy conversion/storage devices, and efficient, environmentally benign, sustainable catalysts.

In FY 2010, continued emphasis will be placed on probing the organizational principles of biological energy transduction and chemical storage systems using advanced molecular imaging and x-ray or neutron methods for structural determination. Of particular interest is the molecular scale characterization of the structure and chemistry of the biopolymers of the plant cell wall, knowledge that is required for the direct catalytic conversion of biomass into chemical fuels. In FY 2010, there is an increase for the application of physical characterization tools to biochemical systems, particularly those relevant to conversion of biomass into fuels.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **Catalysis Science** | **40,412** | **46,506** | **48,139** |

This activity develops the fundamental scientific principles enabling rational catalyst design and chemical transformation control. Research includes the identification of the elementary steps of catalytic reaction mechanisms and their kinetics; construction of catalytic sites at the atomic level; synthesis of ligands, metal clusters, and bio-inspired reaction centers designed to tune molecular-level catalytic activity and selectivity; the study of structure-reactivity relationships of inorganic, organic, or hybrid catalytic materials in solution or supported on solids; the dynamics of catalyst structure relevant to catalyst stability; the experimental determination of potential energy landscapes for catalytic reactions; the development of novel spectroscopic techniques and structural probes for *in situ* characterization of catalytic processes; and the development of theory, modeling, and simulation of catalytic pathways. Capital equipment funding is provided for items such as ultrahigh vacuum equipment with various probes of interfacial structure, spectroscopic analytical instrumentation, specialized cells for *in situ* synchrotron-based experiments, and computational resources.

Catalytic transformations impact an enormous range of DOE mission areas. Particular emphasis is placed on catalysis relevant to the conversion and use of fossil and renewable energy resources and the creation of advanced chemicals. Catalysts are vital in the conversion of crude petroleum and biomass into clean burning fuels and materials. They control the electrocatalytic conversion of fuels into energy in fuel cells and batteries and play important roles in the photocatalytic conversion of energy into chemicals and materials. Catalysts are crucial to creating new, energy-efficient routes for the production of basic chemical feedstocks and value-added chemicals. Environmental applications of catalytic science include minimizing unwanted products and transforming toxic chemicals into benign ones, such as the transformation of chlorofluorocarbons into environmentally acceptable refrigerants.

In FY 2010, research will focus on the chemistry of inorganic, organic, and hybrid porous materials, the nanoscale self-assembly of these systems, and the integration of functional catalytic properties into nanomaterials. New strategies for design of selective catalysts for fuel production from both fossil and renewable biomass feedstocks will be explored. Increased emphasis will be placed on the use of spectroscopy and microscopy to probe both model systems in vacuum and realistic catalytic

| | (dollars in thousands) | |
|---|---|---|
| FY 2008 | FY 2009 | FY 2010 |

sites. Research on catalytic cycles involved in electrochemical energy storage and solar photocatalytic fuel formation will receive increased emphasis. In FY 2010, there is an increase for chemical imaging of operating catalytic systems, experimental and theoretical studies of electrocatalytic processes relevant to solar energy conversion and electrical energy storage, and novel catalytic routes for the conversion of biological feedstocks into chemical fuels.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **Separations and Analysis** | **15,359** | **17,979** | **18,594** |

This activity supports fundamental research covering a broad spectrum of separation concepts, including membrane processes, extraction under both standard and supercritical conditions, adsorption, chromatography, photodissociation, and complexation. Also supported is work to improve the sensitivity, reliability, and productivity of analytical determinations and to develop new approaches to analysis in complex, heterogeneous environments, including techniques that combine chemical selectivity and spatial resolution to achieve chemical imaging. This activity is the nation's most significant long-term investment in the fundamental science underpinning actinide separations and mass spectrometry. The overall goal is to obtain a thorough understanding, at molecular and nanoscale dimensions, of the basic chemical and physical principles involved in separations systems and analytical tools so that their full utility can be realized. Capital equipment funding is provided for items such as lasers for use in sample ionization and chemical imaging, advanced mass spectrometers with nanoprobes, confocal microscopes for sub-diffraction limit resolution, and computational resources.

Work is closely coupled to the DOE's stewardship responsibility for transuranic chemistry; therefore, separation and analysis of transuranic isotopes and their radioactive decay products are important components of the portfolio. Knowledge of molecular-level processes is required to characterize and treat extremely complex radioactive mixtures in, for example, new nuclear fuel systems, and to understand and predict the fate of radioactive contaminants in the environment. Separations are essential to nearly all operations in processing industries and are also necessary for many analytical procedures.

In FY 2010, separations research will focus on fluid flow in nanoscale membranes and the formation of macroscopic separation systems via self-assembly of nanoscale building blocks. Chemical analysis research will emphasize the study of hydrogen separation and hydrogen transport within membrane systems; development of techniques with high spatial, temporal, and chemical resolution; and simultaneous application of multiple analytical techniques. In FY 2010, there is an increase for advanced chemical separations, particularly separation techniques relevant to capture of carbon dioxide and for analytical chemical imaging.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **Heavy Element Chemistry** | **9,002** | **10,744** | **11,111** |

This activity supports research in the chemistry of the heavy elements, including actinides and fission products. The unique molecular bonding of the heavy elements is explored using theory and experiment to elucidate electronic and molecular structures, bond strengths, and chemical reaction rates. Additional emphasis is placed on the chemical and physical properties of actinides to determine solution, interfacial, and solid-state bonding and reactivity; on determinations of the chemical properties of the heaviest actinide and transactinide elements; and on bonding relationships among the actinides, lanthanides, and transition metals. Capital equipment funding is provided for

| | (dollars in thousands) | |
|---|---|---|
| FY 2008 | FY 2009 | FY 2010 |

items such as instruments used to characterize actinide materials (spectrometers, diffractometers, etc.) and equipment to handle the actinides safely in laboratories and at synchrotron light sources.

This activity represents the nation's only funding for basic research in actinide and fission product chemistry and is broadly relevant to the DOE mission. Knowledge of the chemical characteristics of actinide and fission-product materials under realistic conditions provides a basis for advanced fission fuel cycles. Fundamental understanding of the chemistry of these long-lived radioactive species is required to accurately predict and mitigate their transport and fate in environments associated with the storage of radioactive wastes.

In FY 2010, continued emphasis will be placed on bonding and reactivity studies in solutions, solids, nanoparticles, and interfaces, incorporating theory and modeling to understand, predict, and control the chemical bonding and reactivity of the heavy elements, especially under extreme conditions of temperature and radiation fields to be found in advanced nuclear energy systems. Increased study of organo-actinide chemistry may provide new insights into metal-carbon bonds with metals that have large ion sizes, f-orbital bonding, and multiple oxidation states. In FY 2010, there is an increase for enhanced efforts on actinide chemistry and separations science related to advanced nuclear energy systems.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **Geosciences Research** | **20,463** | **23,787** | **24,601** |

This activity supports basic experimental and theoretical research in geochemistry and geophysics. Geochemical research emphasizes fundamental understanding of geochemical processes and reaction rates, focusing on aqueous solution chemistry, mineral-fluid interactions, and isotopic distributions and migration in natural systems. Geophysical research focuses on new approaches to understand the subsurface physical properties of fluids, rocks, and minerals and develops techniques for determining such properties at a distance; it seeks fundamental understanding of wave propagation physics in complex media and the fluid dynamics of complex fluids through porous and fractured subsurface rock units. Application of x-ray and neutron scattering using BES facilities plays a key role in the geochemical and geophysical studies within this activity. The activity also emphasizes incorporating physical and chemical understanding of geological processes into multiscale computational modeling. Capital equipment funding is provided for items such as x-ray and neutron scattering end stations at BES facilities for environmental samples and for augmenting experimental, field, and computational capabilities.

This activity provides the basic research in geosciences that underpins the nation's strategy for understanding and mitigating the terrestrial impacts of energy technologies and thus is relevant to the DOE mission in several ways. It develops the fundamental understanding of geological processes relevant to geological disposal options for byproducts from multiple energy technologies. Knowledge of subsurface geochemical processes is essential to determining the fate and transport properties of harmful elements from possible nuclear or other waste releases. Geophysical imaging methods are needed to measure and monitor subsurface reservoirs for hydrocarbon production or for carbon dioxide storage resulting from large-scale carbon sequestration schemes.

In FY 2010, continued emphasis will be placed on geochemical studies and computational analysis of complex subsurface fluids and solids, including nanophases; understanding the dynamics of fluid flow, particulate transport and associated rock deformation in the deep subsurface; and developing

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |

the ability to integrate multiple data types in predictions of subsurface processes and properties. In FY 2010, there is an increase for solid earth geophysics and geochemistry.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **General Plant Projects (GPP)** | **11,098** | **815** | **843** |

GPP funding is provided for minor new construction, for other capital alterations and additions, and for improvements to land, buildings, and utility systems principally at the Ames Laboratory and the Combustion Research Facility at Sandia National Laboratories. Funding of this type is essential for maintaining the productivity and usefulness of the Department-owned facilities and in meeting requirements for safe and reliable facilities operation. Additional GPP funding is included in the Materials Sciences and Engineering subprogram and the Scientific User Facilities subprogram. The total estimated cost of each GPP project will not exceed $10,000,000.

In FY 2009, non-programmatic GPP funding for ORNL and ANL was transferred to the Science Laboratories Infrastructure program to support the SC Infrastructure Modernization Initiative.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **Energy Frontier Research Centers (EFRCs)**[a] | **—** | **44,700** | **44,700** |

This activity supports those EFRCs with an emphasis on Chemical Sciences, Geosciences, and Energy Biosciences that are coordinated with the ongoing core research activities within the subprogram EFRCs are multi-investigator and multi-disciplinary collaborations that foster, encourage, and accelerate basic research to provide the basis for transformative energy technologies of the future. The EFRC program represents an important implementation of the BES strategic plan for grand challenge and use-inspired energy science that has been set forth in the series of BESAC and Basic Research Needs workshops over the last six years[b]. The scientific challenges emerging from these studies describe a new era of science—an era in which materials functionalities are designed to specifications and chemical transformations are manipulated at will. The EFRCs were established in FY 2009 through a competitive Funding Opportunity Announcement that was open to universities, DOE laboratories, for-profit companies and nonprofit entities. EFRCs bring together the skills and talents of a critical mass of investigators to enable energy relevant, basic research of a scope and complexity that would not be possible with the standard single-investigator or small-group award and thus complement the ongoing BES core research activities. The EFRCs inspire, train, and support leading scientists of the future who will ultimately be called upon to solve the nation's energy challenges in the 21st century.

While EFRCs are inherently multi-disciplinary in nature, this activity includes EFRCs that are focused on design, discovery, control, and characterization of chemical, biochemical, and geological moieties and processes for the advanced conversion of solar energy into chemical fuels; for improved electrochemical storage of energy; for the creation of next-generation biofuels via catalytic chemistry and biochemistry; for the clean and efficient combustion of advanced transportation fuels; and for science-based geological carbon capture and sequestration. Unifying themes in the research include the fundamental understanding of interfacial phenomena underlying the transport of electrons, atoms, molecules, and energy at the nanoscale and the development and application of

[a] A complimentary set of EFRCs is also supported in the Materials Sciences and Engineering subprogram.
[b] http://www.sc.doe.gov/bes/reports/list.html

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |

new experimental and theoretical tools for molecular-scale understanding of complex chemical, biochemical, and geological processes.

In FY 2010, emphasis will be placed on ensuring that the EFRCs established late in FY 2009 are progressing toward their full collaborative and scientific potential using management protocols developed for other large-scale activities.

| | | | |
|---|---|---|---|
| ▪ **Energy Innovation Hub - Fuels from Sunlight** | **—** | **—** | **34,020** |

Nature has understood for nearly 3 billion years how to turn sunlight into energy-rich chemical fuels starting from the abundant feedstocks of water and carbon dioxide. All of the fuels we use today to power our vehicles and create electricity, whether from fossil or biomass resources, are derived from the natural photosynthetic process. While biofuels derived from plant feedstocks avoid the environmental consequences of burning fossil fuels, the scalability and sustainability of this approach remains a concern. More fundamentally, the overall efficiency in converting sunlight to plant material and then converting biomass into fuels is low. Imagine the potential if we could bypass the plant medium entirely and generate fuels directly from sunlight, carbon dioxide, and water just as a plant does. The impact of replacing fossil fuels with bio-inspired fuels created directly from sunlight would be immediate and completely transformative, providing an abundant supply of environmentally benign fuel for our transportation needs. Recognizing this fact, the BESAC report, *New Science for Secure and Sustainable Energy Future,* listed the production of fuels directly from sunlight as one its three strategic goals for which transformational science breakthroughs are urgently needed.

Basic research has provided enormous advances in our understanding of the subtle and complex photochemistry associated with the natural photosynthetic system. Similar advances have been made in purely inorganic photo-catalytic approaches to split water or photoreduce carbon dioxide. Yet, we still lack sufficient knowledge of the natural process and adequate control of artificial systems to design solar fuel generation processes with the efficiency, sustainability, or economic viability required. A Hub focused on making fuels from sunlight would aim at developing a direct solar fuel conversion system with overall conversion efficiency that produces fuels with sufficient energy content to enable the transition to proof-of-concept prototyping. The scale of the scientific challenge associated with this goal is daunting, but not insurmountable, and will require drawing expertise and premier scientific talent from the disciplines of chemistry, physics, materials sciences, biology, and engineering.

In FY 2010, research will be included in the following areas. Potential approaches to the challenge of producing fuels from sunlight that the Hub might adopt include the following:

- Replicating or reverse engineering the natural photosynthetic system with inorganic materials or hybrid bio-inorganic systems. Advances here require a more profound understanding of the subtle and complex chemistry of plant life, particularly in understanding the marvelous ability by which plants regulate the photosynthetic apparatus and repair themselves when damaged, both critical factors in the construction of a robust, man-made solar fuel generator.
- Using solar photovoltaics to drive the splitting of water or the reduction of carbon dioxide in an electrochemical cell, which requires the design and discovery of novel nano-engineered materials

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| (dollars in thousands) | | | |

that catalyze the water splitting reaction and that are efficient, cost effective, environmentally benign, and have long term stability and reliability.

- Artificially connecting biochemical systems that can combine water, sunlight, and even carbon dioxide to produce hydrogen or another chemical fuel in a man-made chemical reactor. The key to this approach is identifying the "software" for the synthetic cell, which can guide the process to the desired product.
- One-time funding of $10,000,000 will be provided for Hub start-up needs, excluding any new construction.

| | | | |
|---|---|---|---|
| **SBIR/STTR** | **—** | **7,809** | **9,068** |

In FY 2008, $5,179,000 and $621,000 were transferred to the SBIR and STTR programs, respectively. The FY 2009 and FY 2010 amounts shown are the estimated requirements for the continuation of the congressionally mandated SBIR and STTR program.

| | | | |
|---|---|---|---|
| **Total, Chemical Sciences, Geosciences, and Energy Biosciences** | **216,747** | **292,870** | **338,357** |

## Explanation of Funding Changes

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| **Chemical Sciences, Geosciences, and Biosciences Research** | |
| ▪ **Atomic, Molecular and Optical Science** | |
| Increased funding is provided for ultrafast science and for the control of quantum systems. | +783 |
| ▪ **Chemical Physics Research** | |
| Increased funding is provided for research related to the combustion of alternative fuels, for emergent behavior in condensed phase systems, and for interfacial science relevant to electrical energy storage, including studies of electrode-electrolyte interfaces (+$1,638,000). | |
| Funding is provided to cover pension payments for ORNL (including Wackenhut) and LBNL ($+1,944,000). | +3,582 |
| ▪ **Solar Photochemistry** | |
| Increased funding is provided for research on inorganic/organic donor-acceptor molecular assemblies and in the use of nanoscale materials in solar photocatalytic generation of chemical fuels. | +1,186 |
| ▪ **Photosynthetic Systems** | |
| Increased funding is provided for solar energy conversion, including research on biological and bio-hybrid systems and enhanced efforts in understanding defect | +612 |

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| tolerance and self-repair in natural photosynthetic systems. | |
| ▪ **Physical Biosciences** | |
| Increased funding is provided for the application of physical characterization tools to biochemical systems. | +588 |
| ▪ **Catalysis Science** | |
| Increased funding is provided for chemical imaging of operating catalytic systems, experimental and theoretical studies of electrocatalytic processes relevant to solar energy conversion and electrical energy storage, and novel catalytic routes for the conversion of biological feedstocks into chemical fuels. | +1,633 |
| ▪ **Separations and Analysis** | |
| Increased funding is provided for advanced chemical separations, particularly separation techniques relevant to capture of carbon dioxide and for analytical chemical imaging. | +615 |
| ▪ **Heavy Element Chemistry** | |
| Increased funding is provided for enhanced efforts on actinide chemistry and separations science related to advanced nuclear energy systems. | +367 |
| ▪ **Geosciences Research** | |
| Increased funding is provided for research in solid earth geophysics and geochemistry. | +814 |
| ▪ **Energy Innovation Hub – Fuels from Sunlight** | |
| Funds are provided for an Energy Innovation Hub focused on making fuels from sunlight to develop a solar fuel conversion system that completely bypasses plants as the medium drawing from disciplines of chemistry physics, materials sciences, biology, and engineering. | +34,020 |
| ▪ **General Plant Projects (GPP)** | |
| Small increase for general plant projects. | +28 |
| **Total, Chemical Sciences, Geosciences and Energy Biosciences Research** | **+44,228** |
| **SBIR/STTR** | |
| Increased funding in SBIR/STTR funding because of an increase in operating expenses. | +1,259 |
| **Total Funding Change, Chemical Sciences, Geosciences, and Energy Biosciences** | **+45,487** |

**Scientific User Facilities**

**Funding Schedule by Activity**[a]

(dollars in thousands)

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| Scientific User Facilities | | | |
| Research | 11,439 | 20,370 | 24,713 |
| Major Items of Equipment | 30,543 | 34,000 | 25,000 |
| Facilities Operations | 666,333 | 718,968 | 742,749 |
| SBIR/STTR | — | 18,632 | 19,329 |
| Total, Scientific User Facilities | 708,315 | 791,970 | 811,791 |

## Description

This subprogram supports the R&D, planning, and operation of scientific user facilities for the development of novel nano-materials and for materials characterization through x-ray, neutron, and electron beam scattering; the former is accomplished through five Nanoscale Science Research Centers and the latter is accomplished through the world's largest suite of synchrotron radiation light source facilities, neutron scattering facilities, and electron-beam microcharacterization centers.

The BES-supported suite of facilities and research centers provide a unique set of analytical tools for studying the atomic structure and functions of complex materials. These facilities provide key capabilities to correlate the microscopic structure of materials with their macroscopic properties. The synchrotron light sources, producing photons largely over the x-ray range, shed light on fundamental aspects of the physical world, investigating energy, momentum, and position using the techniques of spectroscopy, scattering, and imaging applied over various time scales. Neutron sources take advantage of the electrical neutrality and special magnetic properties of the neutron to probe atoms and molecules and their assembly into materials. Electron beam instruments provide the spatial resolution needed to observe individual nanostructures and even single atoms by exploiting the strong interactions of electrons with matter and the ability to readily focus beams of charged particles. The Nanoscale Science Research Centers provide the ability to fabricate complex nanostructures using chemical, biological, and other synthesis techniques, and to characterize them, assemble them, and integrate them into devices.

Annually, the BES user facilities are visited by more than 10,000 scientists and engineers in many fields of science and technology. These facilities provide unique capabilities to the scientific community, and are a critical component of maintaining U.S. leadership in the physical sciences. The light sources are an outstanding example of serving users from a diverse range of disciplines, including physical and life sciences. For example, the life sciences sector of the light sources users increased from less than 10% in 1990's to over 40% in 2008. Also supported are research activities leading to the improvement of today's facilities and better detectors, paving the foundation for the development of next generation facilities.

[a] This table shows the FY 2008 and FY 2009 funding in the new (comparable) budget structure to assist in comparing year-to-year funding trends. A crosswalk of the new and old structure is provided at the end of this chapter, describing in detail the modification to the budget structure.

**Selected FY 2008 Facility Accomplishments**

- *The Spallation Neutron Source (SNS)* continues on its path to megawatt-level beam powers. The SNS raised its beam power to 700 kW, which is four times higher than any other spallation neutron source in the world. In addition, 11 neutron scattering instruments will be available to users in FY 2009. At the *High Flux Isotope Reactor (HFIR)* the new cold source provided beam to new instruments at cold neutron flux levels unsurpassed by any other research reactor facility in the world. The number of instruments at HFIR available to users has increased to nine and the reactor has operated safely and with excellent reliability.

- *Studies at the SNS* of a new class of nanostructured materials—weakly-coupled polyelectrolyte multilayers—show that pH level can trigger release disorders in the film. The results suggest possible applications where macromolecular components can be released through the disordered films, such as in a drug delivery system.

- *Synchrotron radiation light sources.* In FY 2008, there were significant advances in nanoscale imaging. The hard x-ray nanoprobe at the *Advanced Photon Source*, operated jointly with the *Center for Nanoscale Materials*, provides x-ray imaging with an initial spatial resolution of 30 nanometers using zone plate lenses. The coherently focused beams are used to map crystal lattice spacing modulations to determine the strain and crystallographic structure of nanoscale regions of complex materials and devices. The nanobeam x-ray analysis showed that metal surface scales are a mixture of oxides and metal nanoparticles. These nanoparticles can self-assemble into nano-networks forming continuous channels for transport of elements such as carbon and hydrogen through the oxide scales, causing corrosion and embrittlement. Metal oxide scales without spinel phases have been found to prevent the formation of these nanoparticles. Based on these studies laboratory-sized batches of materials have been developed that exhibit as much as ten times longer life than commercial alloys with similar chromium content. These alloys are of considerable interest to the chemical, petrochemical and refining industries.

  X-ray focusing technique has been employed at the *National Synchrotron Light Source* where a compound lens composed of a series of refractive silicon lenses is able to surpass a critical incident x-ray angle limit to deliver superior focusing properties. This is an important step towards the *National Synchrotron Light Source II (NSLS-II)*, a state-of-the-art synchrotron facility in development that will produce x-rays up to 10,000 times brighter than those generated by the current NSLS.

  Research done at the *Advanced Light Source (ALS)* shows that relativistic Dirac particles and the quantum coexist and are in fact highly coupled in electrically insulating single crystalline bismuth antimony alloys. This may be important in the design of new devices for low power consumption spin based electronics technologies and may also provide a basis for quantum computing.

- *Full operations of the five Nanoscale Science Research Centers (NSRC).* The NSRCs hosted more than 1,200 users in FY 2008, resulting in over 400 publications in the scientific literature. These BES facilities have been used to synthesize and characterize new materials. At the *Molecular Foundry* a class of sequence-specific bio-inspired polymers called peptoids have been synthesized from readily available starting materials by solid-phase synthesis and folded into defined structures. Peptoid oligomers and polymers are finding wide applications by a variety of groups in drug discovery, diagnostics, drug delivery, and materials science, since they combine the advantages of proteins with those of synthetic polymers.

Scientists at the *Center for Functional Nanomaterials* discovered a process that enables controlled layer-by-layer deposition of large areas of graphene on the metal substrate, ruthenium. Graphene, an atom-thick honeycomb layer of carbon atoms, has shown exceptional properties with potential for a broad range of applications. For instance, graphene's very high electron mobility at room temperature and its sensitivity to single-molecule gas detection make graphene very promising for applications in electronics and sensing.

An indirect imaging technique was developed at the *Center for Nanophase Material Science* whereby a hidden nanoscale structure can be inferred from the fluctuations of neighboring structures that can be imaged. This technique was used to discover key operational details of a biochemical switch that determines the fate of HIV-infected cells. Another novel method to probe bias-induced phase transitions based on a scanning probe microscopy platform has provided new insights into ferroelectric switching, and also garnered an R&D 100 award.

- *Major advances in imaging at the electron beam micro-characterization and nanoscale science research centers*. An unprecedented 0.05 nm spatial information limit was demonstrated in the course of development of the Transmission Electron Aberration-corrected Microscope (TEAM), a project led by the *National Center for Electron Microscopy* and involved numerous other partners to create the first of a new generation of electron microscopes. Also as part of the TEAM effort, researchers at the *Electron Microscopy Center for Materials* improved by an order of magnitude the resolution of energy-filtered transmission microscopy by correcting for the chromatic aberrations of the electron microscope's lenses. This technique enables the study of variations in chemistry at the sub-nanometer scale which is essential to improving the properties of materials.

## Detailed Program Justification

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| **Research** | **11,439** | **20,370** | **24,713** |
| ▪ **Electron-beam Microcharacterization** | **8,192** | **11,250** | **11,652** |

This activity supports three electron-beam microcharacterization centers, which operate as user facilities, work to develop next-generation electron-beam instrumentation, and conduct corresponding research. These centers are the Electron Microscopy Center for Materials Research at Argonne National Laboratory (ANL), the National Center for Electron Microscopy at Lawrence Berkeley National Laboratory (LBNL), and the Shared Research Equipment program at Oak Ridge National Laboratory (ORNL). Operating funds are provided to enable expert scientific interaction and technical support and to administer a robust user program at these facilities, which are made available to all researchers with access determined via peer review of brief proposals. Capital equipment funding is provided for instruments such as scanning, transmission, and scanning transmission electron microscopes, atom probes and related field ion instruments, related surface characterization apparatus and scanning probe microscopes, and/or ancillary tools such as spectrometers, detectors, and advanced sample preparation equipment.

Electron scattering has key attributes that give such approaches unique advantages and make them complementary to x-ray and neutron beam techniques. These characteristics include strong interactions with matter (allowing the capture of meaningful signals from very small amounts of material, including single atoms under some circumstances) and the ability to readily focus the

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |

charged electron beams using electromagnetic lenses. The net result is unsurpassed spatial resolution and the ability to simultaneously get structural, chemical, and other types of information from subnanometer regions, allowing study of the fundamental mechanisms of catalysis, energy conversion, corrosion, charge transfer, magnetic behavior, and many other processes. All of these are fundamental to understanding and improving materials for energy applications and the associated physical characteristics and changes that govern performance.

In FY 2010, full user operations are supported on the Transmission Electron Aberration Corrected Microscope (TEAM), which will be available to the research community as part of the National Center for Electron Microscopy at LBNL. This instrument leads the world in spatial resolution and embodies the first chromatic aberration corrector in an instrument of this kind, and thus its availability opens new frontiers in imaging of materials on the nanoscale for the broad scientific community. Further research and technique development proceeds using this and other instruments at the Electron Beam Microcharacterization Centers on high-resolution imaging, atomic scale tomography, in-situ experimentation within electron microscopes, strain and segregation in individual nanostructures, and many other related topics.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **Accelerator and Detector Research** | **2,747** | **9,120** | **13,061** |

This activity supports basic research in accelerator physics and x-ray and neutron detectors. Research includes studies of ultra-high brightness electron beams to drive self amplified spontaneous emission free electron lasers, such as the Linac Coherent Light Source (LCLS); collective electron effects, such as micro-bunch instabilities from coherent synchrotron and edge radiation; beam bunching techniques, such as magnetic compression or velocity bunching; fast instruments to determine the structure of femtosecond electron bunches; and detectors capable of acquiring data at very high collection rates.

This activity interacts with BES scientific research that employs synchrotron and neutron sources. It also coordinates with other DOE offices, especially in the funding of capabilities whose cost and complexity require shared support. Research at the Accelerator Test Facility at Brookhaven National Laboratory is jointly funded by the High Energy Physics and BES programs. There is also planned collaboration with the National Science Foundation (NSF) on Energy Recovery Linac (ERL) research. There is a coordinated effort between DOE and NSF to facilitate x-ray detector development. There are ongoing industrial interactions through DOE Small Business Innovation Research and Small Business Technology Transfer (SBIR/STTR) program awards for the development of x-ray detectors and advanced accelerator technology.

Additional funds provided in FY 2010 will increase selected R&D activities related to light sources. These include the physics of gain mechanisms in free-electron lasers (FELs), rapid electron bunch diagnostics, advanced x-ray and neutron detectors, $H^-$ high intensity sources, and accelerator modeling. These projects are essential to the efficient operation and use of present BES x-ray and neutron scattering facilities and to the design of future facilities.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **Nanoscale Science Research Centers** | **500** | **—** | **—** |

Funding for Other Project Costs for the Nanoscale Science Research Centers has been completed.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| **Major Items of Equipment** | **30,543** | **34,000** | **25,000** |
| ▪ **Spallation Neutron Source Instrumentation I (SING I)** | **11,856** | **12,000** | **5,000** |

Funds are provided to continue a Major Item of Equipment with a total estimated cost and total project cost of $68,500,000 for five instruments for the Spallation Neutron Source (SNS). The instrument concepts for the project were competitively selected using a peer review process, and the instruments are being installed at the SNS on a phased schedule between FY 2008–2011.

| | | | |
|---|---|---|---|
| ▪ **Spallation Neutron Source Instrumentation II (SING II)** | **6,000** | **7,000** | **18,000** |

Funds are provided for a Major Item of Equipment with a total estimated cost and total project cost of $60,000,000 to fabricate four instruments to be installed at the SNS. The instrument concepts for the project have been competitively selected using a peer review process. The project is be managed by Oak Ridge National Laboratory. It is anticipated that these instruments will be installed at the SNS on a phased schedule beginning in about FY 2011. The SING II instruments are in addition to the five instruments to be provided by the SING I MIE. The baseline TPC is now approved at the Approve Performance Baseline, CD-2, for three of the four instruments. The FY 2010 Request is for engineering design of the final instrument and fabrication of the others.

| | | | |
|---|---|---|---|
| ▪ **Linac Coherent Light Source Ultrafast Science Instruments (LUSI)** | **6,000** | **15,000** | **—** |

Funds are provided for a Major Item of Equipment with a total project cost of $60,000,000 for three instruments for the Linac Coherent Light Source (LCLS) that will be installed after the LCLS line item project is completed in FY 2010. The technical concepts for the three instruments have been developed in consultation with the scientific community through a series of workshops, conferences, and focused review committees. Instrument designs for the LUSI project have been competitively selected using a peer review process. The project is managed by the SLAC National Accelerator Laboratory. It is anticipated that these three instruments will be installed at the LCLS on a phased schedule between FY 2010–2012. The baseline TPC was approved at Approve Performance Baseline, CD-2. No funds are requested in FY 2010. The project is fully funded as of FY 2009.

| | | | |
|---|---|---|---|
| ▪ **Transmission Electron Aberration Corrected Microscope (TEAM)** | **6,687** | **—** | **—** |

Funding for the Transmission Electron Aberration Corrected Microscope (TEAM) Major Item of Equipment was completed in FY 2008.

| | | | |
|---|---|---|---|
| ▪ **SNS Power Upgrade Project (PUP)** | **—** | **—** | **2,000** |

Funds are provided for a Major Item of Equipment with a preliminary Total Project Cost range of $86,500,000–$98,400,000 for activities to design, build, install, test, and commission the equipment necessary to increase the Spallation Neutron Source (SNS) proton beam energy. CD-0 was approved on November 22, 2004. In addition to the improvements in performance of instruments at the existing high power target station, this power upgrade will enable the eventual construction of a second target station. The existing facility layout and much of the existing SNS equipment was designed and built to meet the requirements of this upgrade.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |

The power upgrade project increases the linac beam energy from 1 GeV to 1.3 GeV. This will be accomplished by adding nine additional high beta cryomodules into the remaining nine open slots in the east end of the superconducting section of the linac. These additional cryomodule units will increase the number of high beta units from twelve to twenty one, allowing the energy to increase. The accelerator tunnel structure and cryogenic system were constructed to allow this upgrade.

FY 2010 funding is provided for engineering design only. Engineering design may include limited fabrication and testing of design concepts.

| | | | |
|---|---|---|---|
| **Facilities Operations** | **666,333** | **718,968** | **742,749** |

This activity supports the operation of the BES scientific user facilities, which consist of light sources, neutron sources, nanoscience centers, and the linear accelerator for the Linac Coherent Light Source project under construction at SLAC. These forefront research facilities require resource commitments well beyond the scope of any non-government institution and open up otherwise inaccessible facets of nature to scientific inquiry. The BES user facilities provide open access to specialized instrumentation and expertise that enable scientific users from universities, national laboratories, and industry to carry out experiments and develop theories that could not be done at their home institutions. For approved, peer-reviewed projects, operating time is available without charge to researchers who intend to publish their results in the open literature. These large-scale user facilities—many of which were justified and built to serve a specific discipline of the physical sciences—have made significant contributions to many other fields of importance to all areas of science and technology, including biology and medicine. The number of users for the synchrotron radiation sources and neutron scattering facilities are shown at the end of this subprogram description, and the number of users for all BES facilities, FY 2000–2008, is provided at: http://www.sc.doe.gov/bes/users.htm. The web sites for all of the BES user facilities are available at: http://www.sc.doe.gov/bes/BESfacilities.htm.

In FY 2010, operation of these scientific user facilities is funded at a level that will permit optimal service to users. Additional funds are provided in FY 2010 for full operation of the SLAC linac and for enhanced capabilities and user support at the new SNS and HFIR neutron beamlines. The light source budget increases reflect the increase in the number of operating beamlines as well as user support at the facilities. Increases in the NSRC budgets reflect full functionality and staffing of the five NSRCs. Small variations in the operations allocations across the five NSRCs reflect differing facility needs and priorities as well as the results of initial operations reviews of the four facilities in FY 2007 and FY 2008. Other project costs are provided for two facilities that are under construction and are described elsewhere in this budget: the Linac Coherent Light Source (LCLS) at SLAC and the National Synchrotron Light Source II at BNL. The Intense Pulsed Neutron Source is closed as a result of competing priorities, and funds are provided to begin the decommissioning of the target assembly.

The facility operations budget request includes operating funds, capital equipment, and accelerator and reactor improvement project (AIP) funding under $5,000,000. AIP funding will support additions and modifications to accelerator and reactor facilities. General plant project (GPP) funding is also required for minor new construction, for other capital alterations and additions, and for improvements to land, buildings, and utility systems. The total estimated cost of each GPP project will not exceed $10,000,000. Capital equipment is needed at the facilities for items such as beam monitors, interlock systems, vacuum systems, beamline front end components, monochromators, and power supplies. A summary of the funding for the facilities is provided below.

| | FY 2008 Actual | FY 2009 Estimate | FY 2010 Estimate |
|---|---|---|---|
| All Facilities | | | |
| Achieved Operating Hours | 29,137 | N/A | N/A |
| Planned Operating Hours | 28,580 | 31,800 | 34,000 |
| Optimal Hours | 35,800 | 34,000 | 34,000 |
| Percent of Optimal Hours | 76% | 94% | 100% |
| Unscheduled Downtime | 8.5% | <10% | <10% |
| Number of Users | 10,538 | 11,345 | 12,390 |

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **Synchrotron Radiation Light Sources** | **328,253** | **366,373** | **375,700** |
| Advanced Light Source, LBNL | 50,194 | 52,016 | 53,869 |
| Advanced Photon Source, ANL | 112,290 | 118,061 | 127,140 |
| National Synchrotron Light Source, BNL | 37,572 | 40,573 | 42,021 |
| National Synchrotron Light Source-II, BNL | 20,000 | 10,000 | 2,000 |
| Stanford Synchrotron Radiation Light Source, SLAC | 32,197 | 34,023 | 35,196 |
| Linac Coherent Light Source (LCLS), SLAC | 15,500 | 20,000 | 20,500 |
| Linac for LCLS, SLAC | 60,500 | 91,700 | 94,974 |

BES operates four light source facilities: the Advanced Light Source at LBNL, the Advanced Photon Source at ANL, the National Synchrotron Light Source at BNL, and the Stanford Synchrotron Radiation Light Source at SLAC. The unique properties of synchrotron radiation include its continuous spectrum, high flux and brightness, and high coherence, which make it an indispensable tool in the exploration of matter. The wavelengths of the emitted photons span a range of dimensions from the atom to biological cells, thereby providing incisive probes for advanced research in a wide range of areas, including materials science, physical and chemical sciences, metrology, geosciences, environmental sciences, biosciences, medical sciences, and pharmaceutical sciences.

Researchers use a variety of experimental techniques when applying synchrotron radiation to their own problems. The fundamental parameters that we use to perceive the physical world (energy, momentum, position, and time) correspond to three broad categories of synchrotron experimental measurement techniques: spectroscopy, scattering, and imaging. By exploiting the short pulse lengths of synchrotron radiation, each technique can also be performed in a timing fashion.

Additional funds are provided in FY 2010 to continue full operation of the SLAC linac and to support operation of the Linac Coherent Light Source (LCLS) starting in the middle of the FY 2010. The budget also reflects an increase in the operating hours as well as user support at the facilities. Other project costs are provided for two facilities under construction - the National Synchrotron Light Source II at BNL and the LCLS at SLAC. The facility operations budget for the light sources also includes operating funds, capital equipment funds, and accelerator and reactor improvement project (AIP) funding under $5,000,000. The AIP funding will support additions and modifications to the accelerator and reactor facilities. Capital equipment is needed at the facilities for items such as beam monitor, interlock systems, vacuum transport systems, beamline front ends and optical components.

| | FY 2008 Actual | FY 2009 Estimate | FY 2010 Estimate |
|---|---|---|---|
| Advanced Light Source | | | |
| Achieved Operating Hours | 4,721 | N/A | N/A |
| Planned Operating Hours | 5,000 | 5,400 | 5,600 |
| Optimal Hours | 5,600 | 5,600 | 5,600 |
| Percent of Optimal Hours | 84.3% | 96.4% | 100% |
| Unscheduled Downtime | 8.3% | <10% | <10% |
| Number of Users | 1,939 | 2,100 | 2,200 |
| | | | |
| Advanced Photon Source | | | |
| Achieved Operating Hours | 4,503 | N/A | N/A |
| Planned Operating Hours | 4,380 | 4,800 | 5,000 |
| Optimal Hours | 5,000 | 5,000 | 5,000 |
| Percent of Optimal Hours | 90% | 96% | 100% |
| Unscheduled Downtime | 2.4% | <10% | <10% |
| Number of Users | 3,270 | 3,500 | 3,700 |
| | | | |
| National Synchrotron Light Source | | | |
| Achieved Operating Hours | 5,006 | N/A | N/A |
| Planned Operating Hours | 4,900 | 5,200 | 5,400 |
| Optimal Hours | 5,400 | 5,400 | 5,400 |
| Percent of Optimal Hours | 93% | 96% | 100% |
| Unscheduled Downtime | 6.0% | <10% | <10% |
| Number of Users | 2,128 | 2,100 | 2,100 |

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| | (dollars in thousands) | | |

| | FY 2008 Actual | FY 2009 Estimate | FY 2010 Estimate |
|---|---|---|---|
| Stanford Synchrotron Radiation Light Source | | | |
| Achieved Operating Hours | 5,027 | N/A | N/A |
| Planned Operating Hours | 4,500 | 5,000 | 5,400 |
| Optimal Hours | 5,400 | 5,400 | 5,400 |
| Percent of Optimal Hours | 93% | 93% | 100% |
| Unscheduled Downtime | 2.9% | <10% | <10% |
| Number of Users | 1,147 | 1,300 | 1,400 |

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **High-Flux Neutron Sources** | **247,880** | **251,403** | **260,246** |
| High Flux Isotope Reactor, ORNL | 54,381 | 58,744 | 60,841 |
| Intense Pulsed Neutron Source, ANL | 8,400 | 4,000 | 4,000 |
| Manuel Lujan, Jr. Neutron Scattering Center, LANL | 10,655 | 11,136 | 11,533 |
| Spallation Neutron Source, ORNL | 174,444 | 177,523 | 183,872 |

BES operates three neutron scattering user facilities—one research reactor, the High Flux Isotope Reactor at ORNL, and two spallation neutron sources, the Spallation Neutron Source at ORNL and the Manuel Lujan Jr. Neutron Scattering Center at LANL. Neutrons are a unique and effective tool for probing the structure of matter.

Beams of neutrons are particularly well-suited for measurement of the positions as well as the fluctuations in the positions of atomis (phonons), and the structure (position and direction) of atomic magnetic moments in solids and the excitations in their magnetic structure (spin waves). Such studies allow physicists to take measurements leading to an understanding of phenomena such as melting, magnetic order, and superconductivity in a variety of solids.

Additional funds are provided in FY 2010 for new operating beamlines at the Spallation Neutron Source and the High Flux Isotope Reactor at ORNL. The budget also reflects an increase in the operating hours as well as user support at the neutron scattering facilities. The Intense Pulsed Neutron Source is closed and funds are provided to continue decommissioning of the target assembly.

The facility operations budget for the neutron sources also includes operating funds, capital equipment funds, and accelerator and reactor improvement project (AIP) funding under $5,000,000. The AIP funding will support additions and modifications to accelerator and reactor facilities. Capital equipment is needed at the facilities for items such as beam monitor, interlock systems, vacuum transport systems, beamline front ends and optical components.

| | FY 2008 Actual | FY 2009 Estimate | FY 2010 Estimate |
|---|---|---|---|
| High Flux Isotope Reactor | | | |
| Achieved Operating Hours | 3,539 | N/A | N/A |
| Planned Operating Hours | 3,100 | 3,900 | 4,500 |
| Optimal Hours | 4,500 | 4,500 | 4,500 |
| Percent of Optimal Hours | 79% | 87% | 100% |
| Unscheduled Downtime | 1.3% | <10% | <10% |
| Number of Users | 258 | 450 | 500 |
| Intense Pulsed Neutron Source | | | |
| Achieved Operating Hours | 1,013 | — | — |
| Planned Operating Hours | 1,000 | — | — |
| Optimal Hours | 3,600 | — | — |
| Percent of Optimal Hours | 28% | — | — |
| Unscheduled Downtime | 4.5% | — | — |
| Number of Users | 89 | — | — |
| Manuel Lujan, Jr. Neutron Scattering Center | | | |
| Achieved Operating Hours | 2,509 | N/A | N/A |
| Planned Operating Hours | 3,000 | 3,500 | 3,600 |
| Optimal Hours | 3,600 | 3,600 | 3,600 |
| Percent of Optimal Hours | 70% | 97% | 100% |
| Unscheduled Downtime | 23.0% | <10% | <10% |
| Number of Users | 261 | 280 | 300 |
| Spallation Neutron Source | | | |
| Achieved Operating Hours | 2,819 | N/A | N/A |
| Planned Operating Hours | 2,700 | 4,000 | 4,500 |
| Optimal Hours | 2,700 | 4,500 | 4,500 |
| Percent of Optimal Hours | 63% | 89% | 100% |
| Unscheduled Downtime | 23.1% | <10% | <10% |
| Number of Users | 165 | 250 | 700 |

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| | (dollars in thousands) | | |
| ▪ **Nanoscale Science Research Centers (NSRCs)** | **90,200** | **101,192** | **106,803** |
| Center for Nanophase Materials Sciences, ORNL | 18,650 | 19,956 | 21,068 |
| Center for Integrated Nanotechnologies, SNL/LANL | 18,000 | 20,100 | 21,218 |
| Molecular Foundry, LBNL | 17,700 | 20,142 | 21,260 |
| Center for Nanoscale Materials, ANL | 18,150 | 20,852 | 21,997 |
| Center for Functional Nanomaterials, BNL | 17,700 | 20,142 | 21,260 |

BES operates five NSRCs to support the synthesis, processing, fabrication, and analysis of materials at the nanoscale: the Center for Nanophase Materials Sciences at ORNL, the Molecular Foundry at LBNL, the Center for Integrated Nanotechnologies at SNL/LANL, the Center for Nanoscale Materials at ANL, and the Center for Functional Nanomaterials at BNL. These facilities are the Department of Energy'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 focuses on a different area of nanoscale research, such as materials derived from or inspired by nature; hard and crystalline materials, including the structure of macromolecules; magnetic and soft materials, including polymers and ordered structures in fluids; and nanotechnology integration. Each center is housed in a new laboratory building near one or more existing BES facilities for x-ray, neutron, or electron scattering. These new buildings contain clean rooms, laboratories for nanofabrication, one-of-a-kind signature instruments, and other instruments not generally available except at major user facilities.

| | FY 2008 Actual | FY 2009 Estimate | FY 2010 Estimate |
|---|---|---|---|
| Number of Users[a] | | | |
| Center for Nanophase Materials Sciences | 404 | 420 | 440 |
| Center for Integrated Nanotechnologies | 272 | 280 | 300 |
| Molecular Foundry | 303 | 315 | 330 |
| Center for Nanoscale Materials | 196 | 210 | 220 |
| Center for Functional Nanomaterials | 106 | 140 | 200 |

[a] Facility operating hours are not measured at user facilities that do not rely on one central machine because such maintenance does not govern how many hours per year the whole facility can accommodate users.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| **SBIR/STTR** | **—** | **18,632** | **19,329** |

In FY 2008, $16,384,000 and $1,966,000 were transferred to the SBIR and STTR programs, respectively. The FY 2009 and FY 2010 amounts shown are the estimated requirements for the continuation of the congressionally mandated SBIR and STTR program.

| | | | |
|---|---|---|---|
| **Total, Scientific User Facilities** | **708,315** | **791,970** | **811,791** |

## Explanation of Funding Changes

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| **Research** | |
| ▪ **Electron-beam Microcharacterization** | |
| Increase is provided for enhanced user operations within the current operating schedules of the facilities, scientific research of facility staff, and development of new instruments or techniques at the facilities. | +402 |
| ▪ **Accelerator and Detector Research** | |
| Increase is provided to expand the portfolio of accelerator and detector research projects, including the physics of gain mechanisms in free-electron lasers (FELs), rapid electron bunch diagnostics, advanced x-ray and neutron detectors, H- high intensity sources, and accelerator modeling. | +3,941 |
| **Total Research** | **+4,343** |
| **Major Items of Equipment** | |
| ▪ **Spallation Neutron Source Instrumentation I** | |
| Scheduled decrease for the Major Item of Equipment for the Spallation Neutron Source Instrumentation I. | -7,000 |
| ▪ **Spallation Neutron Source Instrumentation II** | |
| Scheduled increase for the Major Item of Equipment for the Spallation Neutron Source Instrumentation II. | +11,000 |
| ▪ **Linac Coherent Light Source Ultrafast Science Instruments (LUSI)** | |
| Scheduled decrease for the Major Item of Equipment for the Linac Coherent Light Source Ultrafast Science Instruments. Project was fully funded as of FY 2009. | -15,000 |
| ▪ **SNS Power Upgrade, ORNL** | |
| Increase to begin SNS Power Upgrade MIE | +2,000 |
| **Total, Major Items of Equipment** | **-9,000** |

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| **Facilities Operations** | |
| ▪ **Operation of National User Facilities** | |
| Increase for the Advanced Light Source to support accelerator operations and users. | +1,853 |
| Increase for Advanced Photon Source to support accelerator operations and users. | +9,079 |
| Increase for National Synchrotron Light Source to support accelerator operations and users. | +1,448 |
| Decrease for National Synchrotron Light Source-II – Other Project Costs per the project schedule. | -8,000 |
| Increase for the Stanford Synchrotron Radiation Light Source to support accelerator operations and users. | +1,173 |
| Decrease for Linac Coherent Light Source Other Project Costs per the project schedule ($-5,500,000) and increase to begin operations of the LCLS portion of the Linac that has been commissioned ($+6,000,000). | +500 |
| Increase for SLAC Linac to support operations. | +3,274 |
| Increase for High Flux Isotope Reactor to support reactor operations. | +2,097 |
| Increase for the Manuel Lujan, Jr., Neutron Scattering Center to support target operations and users at approximately the FY 2008 level. | +397 |
| Increase for Spallation Neutron Source to support operations and users | +6,349 |
| Increase for the Center for Nanophase Materials to support operations and users. | +1,112 |
| Increase for the Center for Integrated Nanotechnologies to support operations and users. | +1,118 |
| Increase for the Molecular Foundry to support operations and users. | +1,118 |
| Increase for the Center to Nanoscale Materials to support operations and users. | +1,145 |
| Increase for the Center for Functional Nanomaterials to support operations and users. | +1,118 |
| **Total, Facilities Operations** | **+23,781** |
| **SBIR/STTR** | |
| Increase in SBIR/STTR funding because of an increase in total operating expense. | +697 |
| **Total Funding Change, Scientific User Facilities** | **+19,821** |

## Construction

### Funding Schedule by Activity

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Construction | | | |
| Advanced Light Source User Support Building, LBNL | 4,954 | 11,500 | — |
| Photon Ultrafast Laser Science and Engineering Building Renovation, SLAC | 6,391 | 3,728 | — |
| Project Engineering and Design, Photon Ultrafast Laser Science and Engineering Building Renovation, SLAC | 941 | — | — |
| National Synchrotron Light Source-II, BNL | 29,727 | 93,273 | 139,000 |
| Linac Coherent Light Source, SLAC | 50,889 | 36,967 | 15,240 |
| Center for Functional Nanomaterials, BNL | 363 | — | — |
| Total, Construction | 93,265 | 145,468 | 154,240 |

## Description

Construction is needed to support the research in the BES subprograms. Experiments in support of basic research require that state-of-the-art facilities be built or existing facilities be modified to meet unique research requirements. Reactors, x-ray light sources, and pulsed neutron sources are among the expensive, but necessary, facilities required. The budget for the BES program includes funding for the construction and modification of these facilities.

The new facilities that are in design or under construction—the Linac Coherent Light Source and the National Synchrotron Light Source-II—continue the tradition of BES and SC of providing the most advanced scientific user facilities for the nation's research community in the most cost effective way. All of the BES construction projects are conceived and planned with the broad user community and, during construction, are maintained on schedule and within cost. Furthermore, the construction projects all adhere to the highest standards of safety. These facilities will provide the research community with the tools to fabricate, characterize, and develop new materials and chemical processes to advance basic and applied research across the full range of scientific and technological endeavor, including chemistry, physics, earth science, materials science, environmental science, biology, and biomedical science.

Performance will be measured by meeting the cost and timetables within 10% of the baseline in the construction project data sheet.

### Detailed Justification

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| **Advanced Light Source (ALS) User Support Building, LBNL** | **4,954** | **11,500** | **—** |

The ALS User Support Building (USB) will provide high-quality user support space in sufficient quantity to accommodate the significant growth during the past decade in both the number of beamlines

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |

and the number of ALS users and to accommodate projected future expansion. The USB will provide staging areas for ALS experiments, including valuable high-bay space, wet laboratories, and temporary office space for visiting users.

FY 2008 funds were used to complete preparation of the construction solicitation package(s) for USB and perform Title II design services. The FY 2009 construction funding is being used to award contract(s) as appropriate and continue the design-build construction project efforts. In addition, the project will remediate contaminated soils discovered on the project site during foundation activities. FY 2009 Recovery Act funding is being used to remobilize the design-build construction contractor, erect the steel, complete exterior cladding and commence interior construction project efforts.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **Photon Ultrafast Laser Science and Engineering Building Renovation, SLAC** | **6,391** | **3,728** | **—** |

Photon Ultrafast Laser Science and Engineering (PULSE) is the new center for ultrafast science at the SLAC National Accelerator Laboratory. PULSE represents a major research activity at SLAC that is a key component of the shift in the emphasis of the laboratory from high energy physics to a multi-program laboratory with significant activities in photon science. The PULSE Center will be located in the Central Laboratory building (B040), a mixed use building of laboratories, offices, meeting rooms, and a library. Approximately 18,000 square feet of existing space in the two-story wing of the Central Laboratory building will be renovated to meet the new PULSE programs needs for offices, laboratories, and conference rooms.

The FY 2008 funds were used to begin the PULSE Building Renovation. FY 2009 funding will be used to complete construction.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **Project Engineering and Design, Photon Ultrafast Laser Science and Engineering Building Renovation, SLAC** | **941** | **—** | **—** |

Project Engineering and Design funds for the Photon Ultrafast Laser Science and Engineering Building Renovation, described above, were provided in FY 2008.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **National Synchrotron Light Source-II (NSLS-II), BNL** | **29,727** | **93,273** | **139,000** |

The National Synchrotron Light Source-II (NSLS-II) will be a new synchrotron light source highly optimized to deliver ultra-high brightness and flux and exceptional beam stability. It will also provide advanced insertion devices, optics, detectors, robotics, and an initial suite of scientific instruments. Together, these will enable the study of material properties and functions with a spatial resolution of about 1 nm, an energy resolution of about 0.1 meV, and the ultra-high sensitivity required to perform spectroscopy on a single atom. The NSLS-II project will design, build, and install the accelerator hardware, experimental apparatus, civil construction, and central facilities including offices and laboratories required to produce a new synchrotron light source. It includes a third generation storage ring, full energy injector, experimental areas, an initial suite of scientific instruments, and appropriate support equipment, all housed in a new building.

In FY 2008, Project Engineering and Design (PED) allowed the project to begin detailed design. These funds provide detail estimates of construction based on the approved design, final working drawings and specifications, and provided schedules for construction and procurements.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |

In FY 2009, construction funds will be used to start the civil construction activities, progress on the NSLS-II systems components (e.g. magnet development, storage ring vacuum chambers, and radio frequency systems. In FY 2009, the Recovery Act funds will be used to accelerate the Ring Building civil construction contract activities and several major infrastructure improvements that support the NSLS-II project.

In FY 2010, funds will be used to continue civil construction activities and advancing experimental and accelerator systems. Additional information is provided in the construction project data sheet 07-SC-06.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **Linac Coherent Light Source, SLAC** | **50,889** | **36,967** | **15,240** |

The Linac Coherent Light Source (LCLS) Project will provide laser-like radiation in the x-ray region of the spectrum that is 10 billion times greater in peak brightness than any existing coherent x-ray light source. The LCLS Project will provide the first demonstration of an x-ray Free Electron Laser (FEL) in the 1.5-15 Angstrom range and will apply these extraordinary, high-brightness x-rays to an initial set of scientific problems described below. This will be the world's first such facility. The LCLS will have properties vastly exceeding those of current x-ray sources (both synchrotron radiation light sources and so-called table-top x-ray lasers) in three key areas: peak brightness, coherence (i.e., laser-like properties), and ultrashort pulses. The peak brightness of the LCLS is 10 billion times greater than current synchrotrons, providing $10^{11}$ x-ray photons in a pulse with duration of less than 230 femtoseconds. These characteristics of the LCLS will open new realms of scientific application in the chemical, material, and biological sciences.

In FY 2008, construction funding was used to complete most of the LCLS conventional facilities—including the LCLS Near Experimental Hall, Undulator Hall, Beam Transfer Hall, connecting beam transfer tunnels, and Far Experimental Hall—and for continued procurement and installation of the technical hardware. The project was impacted by the delay and reduction in FY 2007 funding the procurement for the x-ray optics, diagnostics, and end stations and the project revised its cost and schedule baseline in January 2008.

In FY 2009, funding is being used for undulator and photon diagnostics installations, experimental halls installations, renovation of existing buildings at SLAC to provide office space in support of LCLS operations, and installation of technical hardware for x-ray transport system. Commissioning of the facility will also continue on a phased schedule.

In FY 2010, funds will complete the construction and commissioning elements of the project. FY 2011 is expected to be the first full year of LCLS facility operations. Additional information on the LCLS project is provided in the LCLS construction project data sheet, project number 05-R-320.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **Center for Functional Nanomaterials, BNL** | **363** | **—** | **—** |

The Center for Functional Nanomaterials (CFN), a BES Nanoscale Science Research Center, was completed 40 days ahead of schedule and within budget in FY 2008.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **Total, Construction** | **93,265** | **145,468** | **154,240** |

### Explanation of Funding Changes

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| **Advanced Light Source (ALS) User Support Building, LBNL** | |
| Decrease in funding for construction of the ALS User Support Building, as scheduled. | -11,500 |
| **Photon Ultrafast Laser Science and Engineering Building Renovation, SLAC** | |
| Decrease in funding representing the completion of construction in FY 2009, as scheduled. | -3,728 |
| **National Synchrotron Light Source-II (NSLS II), BNL** | |
| Increase in funding to continue construction of the NSLS II project, as scheduled. | +45,727 |
| **Linac Coherent Light Source, SLAC** | |
| Decrease in funding to continue construction of the LCLS project, representing the scheduled ramp down of activities. | -21,727 |
| **Total Funding Change, Construction** | **+8,772** |

## Supporting Information

## Operating Expenses, Capital Equipment and Construction Summary

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Operating Expenses | 1,066,750 | 1,259,706 | 1,368,531 |
| Capital Equipment | 65,543 | 127,702 | 122,029 |
| General Plant Projects | 14,698 | 6,505 | 6,946 |
| Accelerator Improvement Projects | 12,500 | 32,591 | 33,754 |
| Construction | 93,265 | 145,468 | 154,240 |
| Total, Basic Energy Sciences | 1,252,756 | 1,571,972 | 1,685,500 |

## Funding Summary

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Research | 451,517 | 633,206 | 719,745 |
| Scientific User Facilities Operations | 666,333 | 718,968 | 742,749 |
| Major Items of Equipment | 30,543 | 34,000 | 25,000 |
| Construction Projects | 93,265 | 145,468 | 154,240 |
| Other | 11,098 | 40,330 | 43,766 |
| Total, Basic Energy Sciences | 1,252,756 | 1,571,972 | 1,685,500 |

## Scientific User Facility Operations

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Advanced Light Source, LBNL | 50,194 | 52,016 | 53,869 |
| Advanced Photon Source, ANL | 112,290 | 118,061 | 127,140 |
| National Synchrotron Light Source, BNL | 37,572 | 40,573 | 42,021 |
| National Synchrotron Light Source-II, BNL | 20,000 | 10,000 | 2,000 |
| Stanford Synchrotron Radiation Light Source, SLAC | 32,197 | 34,023 | 35,196 |
| High Flux Isotope Reactor, ORNL | 54,381 | 58,744 | 60,841 |
| Intense Pulsed Neutron Source, ANL | 8,400 | 4,000 | 4,000 |
| Manuel Lujan, Jr. Neutron Scattering Center, LANL | 10,655 | 11,136 | 11,533 |
| Spallation Neutron Source, ORNL | 174,444 | 177,523 | 183,872 |
| Center for Nanophase Materials Sciences, ORNL | 18,650 | 19,956 | 21,068 |
| Center for Integrated Nanotechnologies, SNL/LANL | 18,000 | 20,100 | 21,218 |
| Molecular Foundry, LBNL | 17,700 | 20,142 | 21,260 |

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Center for Nanoscale Materials, ANL | 18,150 | 20,852 | 21,997 |
| Center for Functional Nanomaterials, BNL | 17,700 | 20,142 | 21,260 |
| Linac Coherent Light Source (LCLS), SLAC | 15,500 | 20,000 | 20,500 |
| Linac for LCLS, SLAC | 60,500 | 91,700 | 94,974 |
| Total, Scientific User Facility Operations | 666,333 | 718,968 | 742,749 |

## Facilities Users and Hours

| | FY 2008 Actual | FY 2009 Estimate | FY 2010 Estimate |
|---|---|---|---|
| Advanced Light Source | | | |
| Achieved Operating Hours | 4,721 | N/A | N/A |
| Planned Operating Hours | 5,000 | 5,400 | 5,600 |
| Optimal Hours | 5,600 | 5,600 | 5,600 |
| Percent of Optimal Hours | 84.3% | 96.4% | 100% |
| Unscheduled Downtime | 8.3% | <10% | <10% |
| Number of Users | 1,939 | 2,100 | 2,200 |
| Advanced Photon Source | | | |
| Achieved Operating Hours | 4,503 | N/A | N/A |
| Planned Operating Hours | 4,380 | 4,800 | 5,000 |
| Optimal Hours | 5,000 | 5,000 | 5,000 |
| Percent of Optimal Hours | 90% | 96% | 100% |
| Unscheduled Downtime | 2.4% | <10% | <10% |
| Number of Users | 3,270 | 3,500 | 3,700 |
| National Synchrotron Light Source | | | |
| Achieved Operating Hours | 5,006 | N/A | N/A |
| Planned Operating Hours | 4,900 | 5,200 | 5,400 |
| Optimal Hours | 5,400 | 5,400 | 5,400 |
| Percent of Optimal Hours | 93% | 96% | 100% |
| Unscheduled Downtime | 6.0% | <10% | <10% |
| Number of Users | 2,128 | 2,100 | 2,100 |

| | FY 2008 Actual | FY 2009 Estimate | FY 2010 Estimate |
|---|---|---|---|
| Stanford Synchrotron Radiation Light Source | | | |
| Achieved Operating Hours | 5,027 | N/A | N/A |
| Planned Operating Hours | 4,500 | 5,000 | 5,400 |
| Optimal Hours | 5,400 | 5,400 | 5,400 |
| Percent of Optimal Hours | 93% | 93% | 100% |
| Unscheduled Downtime | 2.9% | <10% | <10% |
| Number of Users | 1,147 | 1,300 | 1,400 |
| | | | |
| High Flux Isotope Reactor | | | |
| Achieved Operating Hours | 3,539 | N/A | N/A |
| Planned Operating Hours | 3,100 | 3,900 | 4,500 |
| Optimal Hours | 4,500 | 4,500 | 4,500 |
| Percent of Optimal Hours | 79% | 87% | 100% |
| Unscheduled Downtime | 1.3% | <10% | <10% |
| Number of Users | 258 | 450 | 500 |
| | | | |
| Intense Pulsed Neutron Source | | | |
| Achieved Operating Hours | 1,013 | — | — |
| Planned Operating Hours | 1,000 | — | — |
| Optimal Hours | 3,600 | — | — |
| Percent of Optimal Hours | 28% | — | — |
| Unscheduled Downtime | 4.5% | — | — |
| Number of Users | 89 | — | — |
| | | | |
| Manuel Lujan, Jr. Neutron Scattering Center | | | |
| Achieved Operating Hours | 2,509 | N/A | N/A |
| Planned Operating Hours | 3,000 | 3,500 | 3,600 |
| Optimal Hours | 3,600 | 3,600 | 3,600 |
| Percent of Optimal Hours | 70% | 97% | 100% |
| Unscheduled Downtime | 23.0% | <10% | <10% |
| Number of Users | 261 | 280 | 300 |

| | FY 2008 Actual | FY 2009 Estimate | FY 2010 Estimate |
|---|---|---|---|
| Spallation Neutron Source | | | |
| Achieved Operating Hours | 2,819 | N/A | N/A |
| Planned Operating Hours | 2,700 | 4,000 | 4,500 |
| Optimal Hours | 2,700 | 4,500 | 4,500 |
| Percent of Optimal Hours | 63% | 89% | 100% |
| Unscheduled Downtime | 23.1% | <10% | <10% |
| Number of Users | 165 | 250 | 700 |
| Center for Nanophase Materials Sciences[a] | | | |
| Number of Users | 404 | 420 | 440 |
| Center for Integrated Nanotechnologies[a] | | | |
| Number of Users | 272 | 280 | 300 |
| Molecular Foundry[a] | | | |
| Number of Users | 303 | 315 | 330 |
| Center for Nanoscale Materials[a] | | | |
| Number of Users | 196 | 210 | 220 |
| Center for Functional Nanomaterials[a] | | | |
| Number of Users | 106 | 140 | 200 |
| Total, All Facilities | | | |
| Achieved Operating Hours | 29,137 | N/A | N/A |
| Planned Operating Hours | 28,580 | 31,800 | 34,000 |
| Optimal Hours | 35,800 | 34,000 | 34,000 |
| Percent of Optimal Hours | 76% | 94% | 100% |
| Unscheduled Downtime | 8.5% | <10% | <10% |
| Number of Users | 10,538 | 11,345 | 12,390 |

[a] Facility operating hours are not measured at user facilities that do not rely on one central machine because such maintenance does not govern how many hours per year the whole facility can accommodate users.

## Major Items of Equipment

(dollars in thousands)

| | Prior Years | FY 2008 | FY 2009 | FY 2009 Additional Approp. | FY 2010 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| Spallation Neutron Source Instrumentation I (31MK), ORNL[a] | | | | | | | |
| TEC/TPC | 39,244 | 11,856 | 12,000 | — | 5,000 | 400 | 68,500 |
| Spallation Neutron Source Instrumentation II (71RB), ORNL[b] | | | | | | | |
| TEC/TPC | 500 | 6,000 | 7,000 | — | 18,000 | 28,500 | 60,000 |
| Linac Coherent Light Source Instrumentation (71RA), SLAC[c] | | | | | | | |
| TEC | 500 | 6,000 | 15,000 | +33,600 | — | — | 55,100 |
| OPC | 4,900 | — | — | — | — | — | 4,900 |
| TPC | 5,400 | 6,000 | 15,000 | +33,600 | — | — | 60,000 |
| Transmission Electron Aberration Corrected Microscope (61PC), LBNL | | | | | | | |
| TEC | 5,500 | 6,100 | — | — | — | — | 11,600 |
| OPC | 14,900 | 587 | — | — | — | — | 15,487 |
| TPC | 20,400 | 6,687 | — | — | — | — | 27,087 |
| SNS Power Upgrade Project ORNL | | | | | | | |
| TEC | — | — | — | — | 2,000 | TBD | TBD |
| OPC | — | — | — | — | — | TBD | TBD |
| TPC | — | — | — | — | 2,000 | TBD | TBD |
| Total, Major Items of Equipment | | | | | | | |
| TEC | | 29,956 | 34,000 | +33,600 | 25,000 | | |
| OPC | | 587 | — | — | — | | |
| TPC | | 30,543 | 34,000 | +33,600 | 25,000 | | |

[a] This FY 2003 MIE includes five instruments: High-Pressure Diffractometer, High-Resolution Chopper Spectrometer, Single-Crystal Diffractometer, Disordered Materials Diffractometer, and Hybrid Polarized Spectrometer.
[b] Mission Need (CD-0) was approved on October 31, 2005 with a TPC range of $40–60M. The baseline TPC will be approved at CD-2 (Approve Performance Baseline).
[c] Mission Need (CD-0) was approved on August 10, 2005 with a TPC range of $50–60M. The baseline TPC will be approved at CD-2 (Approve Performance Baseline).

## Construction Projects

(dollars in thousands)

| | Prior Years | FY 2008 | FY 2009 | FY 2009 Additional Approp. | FY 2010 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| 08-SC-01 Advanced Light Source User Support Building, LBNL | | | | | | | |
| TEC | 1,500 | 4,954 | 11,500 | 14,546 | — | — | 32,500[a] |
| OPC | 2,480 | — | 4 | 136 | — | — | 2,620 |
| TPC | 3,980 | 4,954 | 11,504 | 14,682 | — | — | 35,120 |
| 08-SC-10 PED, Photon Ultrafast Laser Science and Engineering Building Renovation, SLAC | | | | | | | |
| TEC/TPC | — | 941 | — | — | — | — | 941 |
| 08-SC-11 Photon Ultrafast Laser Science and Engineering Building Renovation, SLAC | | | | | | | |
| TEC | — | 6,391 | 3,728 | — | — | — | 10,119 |
| OPC | — | 100 | 40 | — | — | — | 140 |
| TPC | — | 6,491 | 3,768 | — | — | — | 10,259 |
| 07-SC-06, National Synchrotron Light Source-II, BNL | | | | | | | |
| TEC | 3,000 | 29,727 | 93,273 | 150,000 | 139,000 | 376,200 | 791,200 |
| OPC | 27,800 | 20,000 | 10,000 | — | 2,000 | 61,000 | 120,800 |
| TPC | 30,800 | 49,727 | 103,273 | 150,000 | 141,000 | 437,200 | 912,000 |
| 05-R-320 Linac Coherent Light Source, SLAC | | | | | | | |
| TEC | 248,904 | 50,889 | 36,967 | — | 15,240 | — | 352,000[b] |
| OPC | 24,000 | 15,500 | 17,000 | — | 11,500 | — | 68,000 |
| TPC | 272,904 | 66,389 | 53,967 | — | 26,740 | — | 420,000 |
| 05-R-321 Center for Functional Nanomaterials, BNL | | | | | | | |
| TEC | 79,334 | 363 | — | — | — | — | 79,697[c] |
| OPC | 800 | 500 | — | — | — | — | 1,300 |
| TPC | 80,134 | 863 | — | — | — | — | 80,997 |

[a] Includes $1,500,000 of PED included in the 07-SC-12 PED, LBNL Advanced Light Source User Support Building datasheet.
[b] Includes 35,974,000 of PED included in the 03-SC-002 PED, SLAC, Linac Coherent Light Source datasheet.
[c] Includes $5,966,000 of PED included in the 02-SC-002 PED, Nanoscale Science Research Centers datasheet.

(dollars in thousands)

| | Prior Years | FY 2008 | FY 2009 | FY 2009 Additional Approp. | FY 2010 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| Total, Construction | | | | | | | |
| TEC | | 93,265 | 145,468 | 164,546 | 154,240 | | |
| OPC | | 36,100 | 27,044 | 136 | 13,500 | | |
| TPC | | 129,365 | 172,512 | 164,682 | 167,740 | | |

## Scientific Employment

(estimated)

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| # of University Grants | 1,000 | 1,200 | 1,300 |
| Average Size per year | 150,000 | 175,000 | 175,000 |
| # Permanent Ph.D's (FTEs) | 3,650 | 4,570 | 4,910 |
| # Postdoctoral Associates (FTEs) | 960 | 1,270 | 1,390 |
| # Graduate Students (FTEs) | 1,490 | 2,000 | 2,200 |

## Budget Structure Funding Crosswalk

(dollars in thousands)

| | FY 2008 Current Approp. | FY 2008 Comp. Adjust. | FY 2008 Comp. Approp. | FY 2009 Current Approp. | FY 2009 Comp. Adjust. | FY 2009 Comp. Approp. | FY 2010 Request |
|---|---|---|---|---|---|---|---|
| Materials Sciences and Engineering | | | | | | | |
| Materials Sciences and Engineering Research | | | | | | | |
| Experimental Condensed Matter Physics | 40,628 | — | 40,628 | 46,398 | — | 46,398 | 51,387 |
| Theoretical Condensed Matter Physics | 27,255 | — | 27,255 | 29,448 | — | 29,448 | 30,455 |
| Mechanical Behavior and Radiation Effects | 13,268 | — | 13,268 | 14,336 | — | 14,336 | 14,826 |
| Physical Behavior of Materials | 28,226 | — | 28,226 | 30,498 | — | 30,498 | 31,541 |
| Neutron and X-Ray Scattering | 40,311 | -8,500 | 31,811 | 46,971 | — | 46,971 | 48,613 |
| Electron and Scanning Probe Microscopies | 16,635 | — | 16,635 | 20,474 | — | 20,474 | 21,174 |
| Experimental Program to Stimulate Competitive Research (EPSCoR) | 14,680 | — | 14,680 | 16,755 | — | 16,755 | 8,520 |
| Synthesis and Processing Science | 15,587 | — | 15,587 | 16,841 | — | 16,841 | 17,417 |
| Materials Chemistry and Biomolecular Materials | 46,339 | — | 46,339 | 51,569 | — | 51,569 | 53,333 |
| Energy Frontier Research Centers (EFRCs) | — | — | — | 55,300 | — | 55,300 | 55,300 |
| Electron-beam Microcharacterization | 8,192 | -8,192 | — | 11,250 | -11,250 | — | — |
| Energy Innovation Hub - Batteries and Energy Storage | — | — | — | — | — | — | 34,020 |
| Accelerator and Detector Research | 2,747 | -2,747 | — | 9,120 | -9,120 | — | — |
| Nanoscale Science Research Centers (OPC) | 500 | -500 | — | — | — | — | — |
| Spallation Neutron Source Instrumentation I (SING I) | 11,856 | -11,856 | — | 7,000 | -7,000 | — | — |
| Spallation Neutron Source Instrumentation II(SING II) | 6,000 | -6,000 | — | 12,000 | -12,000 | — | — |
| Linac Coherent Light Source Ultrafast Science Instruments (LUSI) | 6,000 | -6,000 | — | 15,000 | -15,000 | — | — |

| | (dollars in thousands) | | | | | | |
|---|---|---|---|---|---|---|---|
| | FY 2008 Current Approp. | FY 2008 Comp. Adjust. | FY 2008 Comp. Approp. | FY 2009 Current Approp. | FY 2009 Comp. Adjust. | FY 2009 Comp. Approp. | FY 2010 Request |
| Transmission Electron Aberration Corrected Microscope (TEAM) | 6,687 | -6,687 | — | — | — | — | — |
| General Plant Projects | — | — | — | 4,243 | — | 4,243 | 4,604 |
| Total, Materials Sciences and Engineering Research | 284,911 | -50,482 | 234,429 | 387,203 | -54,370 | 332,833 | 371,190 |
| Facilities Operations | | | | | | | |
| Advanced Light Source, LBNL | 50,194 | -50,194 | — | 52,016 | -52,016 | — | — |
| Advanced Photon Source, ANL | 112,290 | -112,290 | — | 118,061 | -118,061 | — | — |
| National Synchrotron Light Source, BNL | 37,572 | -37,572 | — | 40,573 | -40,573 | — | — |
| National Synchrotron Light Source-II, BNL | 20,000 | -20,000 | — | 10,000 | -10,000 | — | — |
| Stanford Synchrotron Radiation Light Source, SLAC | 32,197 | -32,197 | — | 34,023 | -34,023 | — | — |
| Linac Coherent Light Source (LCLS), SLAC | 15,500 | -15,500 | — | 20,000 | -20,000 | — | — |
| Linac for LCLS, SLAC | 60,500 | -60,500 | — | 91,700 | -91,700 | — | — |
| High Flux Isotope Reactor, ORNL | 54,381 | -54,381 | — | 58,744 | -58,744 | — | — |
| Intense Pulsed Neutron Source, ANL | 8,400 | -8,400 | — | 4,000 | -4,000 | — | — |
| Manuel Lujan, Jr. Neutron Scattering Center, LANL | 10,655 | -10,655 | — | 11,136 | -11,136 | — | — |
| Spallation Neutron Source, ORNL | 165,944 | -165,944 | — | 177,523 | -177,523 | — | — |
| Center for Nanophase Materials Sciences, ORNL | 18,650 | -18,650 | — | 19,956 | -19,956 | — | — |
| Center for Integrated Nanotechnologies, SNL/LANL | 18,000 | -18,000 | — | 20,100 | -20,100 | — | — |
| Molecular Foundry, LBNL | 17,700 | -17,700 | — | 20,142 | -20,142 | — | — |
| Center for Nanoscale Materials, ANL | 18,150 | -18,150 | — | 20,852 | -20,852 | — | — |
| Center for Functional Nanomaterials, BNL | 17,700 | -17,700 | — | 20,142 | -20,142 | — | — |
| Total, Facilities Operation | 657,833 | -657,833 | — | 718,968 | -718,968 | — | — |
| SBIR/STTR | — | — | — | 27,463 | -18,632 | 8,831 | 9,922 |
| Total, Materials Sciences and Engineering Research | 942,744 | -708,315 | 234,429 | 1,133,634 | -791,970 | 341,664 | 381,112 |

(dollars in thousands)

| | FY 2008 Current Approp. | FY 2008 Comp. Adjust. | FY 2008 Comp. Approp. | FY 2009 Current Approp. | FY 2009 Comp. Adjust. | FY 2009 Comp. Approp. | FY 2010 Request |
|---|---|---|---|---|---|---|---|
| Chemical Sciences, Geosciences, and Energy Biosciences | | | | | | | |
| Chemical Sciences, Geosciences, and Energy Biosciences Research | | | | | | | |
| Atomic, Molecular, and Optical Science | 18,353 | — | 18,353 | 22,886 | — | 22,886 | 23,669 |
| Chemical Physics Research | 34,006 | +6,755 | 40,761 | 47,886 | — | 47,886 | 51,468 |
| Solar Photochemistry | 30,479 | — | 30,479 | 34,685 | — | 34,685 | 35,871 |
| Photosynthetic Systems | 15,715 | — | 15,715 | 17,884 | — | 17,884 | 18,496 |
| Physical Biosciences | 15,105 | — | 15,105 | 17,189 | — | 17,189 | 17,777 |
| Catalysis Science | 40,412 | — | 40,412 | 46,506 | — | 46,506 | 48,139 |
| Separations and Analysis | 15,359 | — | 15,359 | 17,979 | — | 17,979 | 18,594 |
| Heavy Element Chemistry | 9,002 | — | 9,002 | 10,744 | — | 10,744 | 11,111 |
| Geosciences Research | 20,463 | — | 20,463 | 23,787 | — | 23,787 | 24,601 |
| General Plant Projects | 11,098 | — | 11,098 | 815 | — | 815 | 843 |
| Energy Frontier Research Centers (EFRCs) | — | — | — | 44,700 | — | 44,700 | 44,700 |
| Energy Innovation Hub – Fuels from Sunlight | — | — | — | — | — | — | 34,020 |
| Total, Chemical Sciences, Geosciences, and Energy Biosciences Research | 209,992 | +6,755 | 216,747 | 285,061 | — | 285,061 | 329,289 |
| Facilities Operations | | | | | | | |
| Combustion Research Facility | 6,755 | -6,755 | — | — | — | — | — |
| SBIR/STTR | — | — | — | 7,809 | — | 7,809 | 9,068 |
| Total, Chemical Sciences, Geosciences, and Energy Biosciences | 216,747 | — | 216,747 | 292,870 | — | 292,870 | 338,357 |
| Scientific User Facilities | | | | | | | |
| Research | | | | | | | |
| Electron-Beam Microcharacterization | — | +8,192 | 8,192 | — | +11,250 | 11,250 | 11,652 |
| Accelerator and Detector Research | — | +2,747 | 2,747 | — | +9,120 | 9,120 | 13,061 |
| Nanoscale Science Research Centers (OPC) | — | +500 | 500 | — | — | — | — |
| Total, Research | — | +11,439 | 11,439 | — | +20,370 | 20,370 | 24,713 |

(dollars in thousands)

| | FY 2008 Current Approp. | FY 2008 Comp. Adjust. | FY 2008 Comp. Approp. | FY 2009 Current Approp. | FY 2009 Comp. Adjust. | FY 2009 Comp. Approp. | FY 2010 Request |
|---|---|---|---|---|---|---|---|
| Major Items of Equipment | | | | | | | |
| Spallation Neutron Source Instrumentation I (SING I) | — | +11,856 | 11,856 | — | +7,000 | 7,000 | — |
| Spallation Neutron Source Instrumentation II (SING II) | — | +6,000 | 6,000 | — | +12,000 | 12,000 | 5,000 |
| Linac Coherent Light Source Ultrafast Science Instruments (LUSI) | — | +6,000 | 6,000 | — | +15,000 | 15,000 | 18,000 |
| Transmission Electron Aberration Corrected Microscope (TEAM) | — | +6,687 | 6,687 | — | — | — | — |
| SNS Power Upgrade Project (PUP) | — | — | — | — | — | — | 2,000 |
| Total, Major Items of Equipment | — | +30,543 | 30,543 | — | +34,000 | 34,000 | 25,000 |
| Facilities Operations | | | | | | | |
| Advanced Light Source, LBNL | — | +50,194 | 50,194 | — | +52,016 | 52,016 | 53,869 |
| Advanced Photon Source, ANL | — | +112,290 | 112,290 | — | +118,061 | 118,061 | 127,140 |
| National Synchrotron Light Source, BNL | — | +37,572 | 37,572 | — | +40,573 | 40,573 | 42,021 |
| National Synchrotron Light Source-II, BNL | — | +20,000 | 20,000 | — | +10,000 | 10,000 | 2,000 |
| Stanford Synchrotron Radiation Light Source, SLAC | — | +32,197 | 32,197 | — | +34,023 | 34,023 | 35,196 |
| Linac Coherent Light Source (LCLS), SLAC | — | +15,500 | 15,500 | — | +20,000 | 20,000 | 20,500 |
| Linac for LCLS, SLAC | — | +60,500 | 60,500 | — | +91,700 | 91,700 | 94,974 |
| High Flux Isotope Reactor, ORNL | — | +54,381 | 54,381 | — | +58,744 | 58,744 | 60,841 |
| Intense Pulsed Neutron Source, ANL | — | +8,400 | 8,400 | — | +4,000 | 4,000 | 4,000 |
| Manuel Lujan, Jr. Neutron Scattering Center, LANL | — | +10,655 | 10,655 | — | +11,136 | 11,136 | 11,533 |
| Spallation Neutron Source, ORNL | — | +174,444 | 174,444 | — | +177,523 | 177,523 | 183,872 |
| Center for Nanophase Materials Sciences, ORNL | — | +18,650 | 18,650 | — | +19,956 | 19,956 | 21,068 |

(dollars in thousands)

| | FY 2008 Current Approp. | FY 2008 Comp. Adjust. | FY 2008 Comp. Approp. | FY 2009 Current Approp. | FY 2009 Comp. Adjust. | FY 2009 Comp. Approp. | FY 2010 Request |
|---|---|---|---|---|---|---|---|
| Center for Integrated Nanotechnologies, SNL/LANL | — | +18,000 | 18,000 | — | +20,100 | 20,100 | 21,218 |
| Molecular Foundry, LBNL | — | +17,700 | 17,700 | — | +20,142 | 20,142 | 21,260 |
| Center for Nanoscale Materials, ANL | — | +18,150 | 18,150 | — | +20,852 | 20,852 | 21,997 |
| Center for Functional Nanomaterials, BNL | — | +17,700 | 17,700 | — | +20,142 | 20,142 | 21,260 |
| Total, Facilities Operations | — | +666,333 | 666,333 | — | +718,968 | 718,968 | 742,749 |
| SBIR/STTR | — | — | — | — | +18,632 | 18,632 | 19,329 |
| Total, Scientific User Facilities | — | +708,315 | 708,315 | — | +791,970 | 791,970 | 811,791 |
| Construction | | | | | | | |
| Advanced Light Source User Support Building, LBNL | 4,954 | — | 4,954 | 11,500 | — | 11,500 | — |
| Photon Ultrafast Laser and Science and Engineering Building Renovation, SLAC | 6,391 | — | 6,391 | 3,728 | — | 3,728 | — |
| Project Engineering and Design, Photon Ultrafast Laser and Science and Engineering Building Renovation, SLAC | 941 | — | 941 | — | — | — | — |
| National Synchrotron Light Source-II, BNL | 29,727 | — | 29,727 | 93,273 | — | 93,273 | 139,000 |
| Linac Coherent Light Source, SLAC | 50,889 | — | 50,889 | 36,967 | — | 36,967 | 15,240 |
| Center for Functional Materials, BNL | 363 | — | 363 | — | — | — | — |
| Total, Construction | 93,265 | — | 93,265 | 145,468 | — | 145,468 | 154,240 |
| Total, Basic Energy Sciences | 1,252,756 | — | 1,252,756 | 1,571,972 | — | 1,571,972 | 1,685,500 |

**07-SC-06, National Synchrotron Light Source II (NSLS-II)**
**Brookhaven National Laboratory, Upton, New York**
**Project Data Sheet is for PED/Construction**

## 1. Significant Changes

The most recent DOE O 413.3A approved Critical Decision (CD) is CD-3, Start of Construction, which was approved on January 9, 2009, with a Total Project Cost (TPC) of $912,000,000.

A Federal Project Director has been assigned to this project. The Federal Project Director is pursuing the appropriate certification level.

This PDS is an update of the FY 2009 PDS.

## 2. Design, Construction, and D&D Schedule

| | CD-0 | CD-1 | (Design/PED Complete) | CD-2 | CD-3 | CD-4 |
|---|---|---|---|---|---|---|
| FY 2007 | 08/25/2005 | 1Q FY 2007 | 4Q FY 2008 | TBD | TBD | TBD |
| FY 2008 | 08/25/2005 | 2Q FY 2007 | 2Q FY 2009 | TBD | TBD | TBD |
| FY 2009 | 08/25/2005 | 07/12/2007 | 2Q FY 2009 | 2Q FY 2008 | 2Q FY 2009 | 3Q FY 2015 |
| FY 2010 | 08/25/2005 | 07/12/2007 | 2Q FY 2009 | 01/18/2008 | 01/09/2009 | 3Q FY 2015 |

CD-0 – Approve Mission Need
CD-1 – Approve Alternative Selection and Cost Range
CD-2 – Approve Performance Baseline
CD-3 – Approved Start of Construction
CD-4 – Approve Project Completion

| | D&D Start | D&D Complete | Performance Baseline Validation |
|---|---|---|---|
| FY 2007 | N/A | N/A | — |
| FY 2008 | N/A | N/A | — |
| FY 2009 | N/A | N/A | 12/11/2007 |
| FY 2010 | N/A | N/A | 12/11/2007 |

D&D Start – Not Applicable to this project
D&D Complete – Not Applicable to this project

## 3. Baseline and Validation Status

(dollars in thousands)

| | TEC, PED | TEC, Construction | TEC, Total | OPC Except D&D | OPC D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2007 | 75,000 | TBD | TBD | TBD | TBD | TBD | TBD |
| FY 2008 | 75,000 | TBD | TBD | TBD | TBD | TBD | TBD |
| FY 2009 | 60,000 | 731,200 | 791,200 | 120,800 | — | 120,800 | 912,000 |
| FY 2010 | 60,000 | 731,200 | 791,200 | 120,800 | — | 120,800 | 912,000 |

## 4. Project Description, Justification, and Scope

The National Synchrotron Light Source II (NSLS-II) will be a new synchrotron light source, highly optimized to deliver ultra-high brightness and flux and exceptional beam stability. It will also provide advanced insertion devices, optics, detectors, robotics, and an initial suite of scientific instruments. Together, these will enable the study of material properties and functions with a spatial resolution of about 1 nm, an energy resolution of about 0.1 meV, and the ultra-high sensitivity required to perform spectroscopy on a single atom.

The NSLS-II project will design, build, and install the accelerator hardware, experimental apparatus, civil construction, and central facilities including offices and laboratories required to produce a new synchrotron light source. It includes a third generation storage ring, full energy injector, experimental areas, an initial suite of scientific instruments, and appropriate support equipment, all housed in a new building.

Major advances in energy technologies will require scientific breakthroughs in developing new materials with advanced properties. A broad discussion is given in several recent reports, including the Basic Energy Sciences (BES) Advisory Committee reports entitled *Opportunities for Catalysis in the 21$^{st}$ Century*, *Basic Research Needs to Assure a Secure Energy Future*, *Basic Research Needs for the Hydrogen Economy*, and *Basic Research Needs for Solar Energy Utilization*, in addition to the report of the Nanoscale Science, Engineering, and Technology Subcommittee of the National Science and Technology Committee entitled *Nanoscience Research for Energy Needs*.

Collectively, these reports underscore the need to develop new tools that will allow the characterization of the atomic and electronic structure, the chemical composition, and the magnetic properties of materials with nanoscale resolution. Needed are non-destructive tools to image and characterize structures and interfaces below the surface, and these tools must operate in a wide range of temperature and harsh environments. The absence of any tool possessing these combined capabilities was identified as a key barrier to progress in the 1999 BES report *Nanoscale Science, Engineering and Technology Research Directions*.

In order to fill this capability gap, the Office of Science has determined that its mission requires a synchrotron light source that will enable the study of material properties and functions, particularly materials at the nanoscale, at a level of detail and precision never before possible. NSLS-II will provide these capabilities. Only x-ray methods have the potential of satisfying all of these requirements, but advances both in x-ray optics and in x-ray brightness and flux are required to achieve a spatial resolution of 1 nm and an energy resolution of 0.1 meV.

There are no alternative tools with a spatial resolution of 1 nm and energy resolution of 0.1 meV that also have the required capabilities of being non-destructive and able to image and characterize buried structures and interfaces in a wide range of temperatures and harsh environments. An analysis found that upgrading existing light sources was either impossible or not cost effective. In the case of NSLS-I, it was found that it would be impossible to upgrade this light source due to numerous technical difficulties, including accelerator physics and infrastructure constraints, such as its small circumference, which limit the feasible in-place upgrade options.

The key performance parameters are defined in the project execution plan. The NSLS-II project is expected to: deliver an electron energy of 3.0 giga-electron volts with a stored current of 25 milliamps; build a third generation storage ring of approximately one half mile in circumference and experimental and operations facilities with a total conventional construction of approximately 400 thousand gross square feet; and include an initial suite of six beamlines ready for commissioning.

Research and development activities funded under Other Project Costs will address technical risk in several key areas including energy resolution, spatial resolution, and storage ring magnets.

Project Engineering and Design funds were used to complete the detailed design, including detailed estimates of construction based on the approved design, final working drawings and specifications, and schedules for construction and procurements.

FY 2009 construction funds will be used to start the civil construction activities and continue progress on the NSLS-II systems components (e.g. magnet development, storage ring vacuum chambers, and radio frequency systems).

The American Recovery and Reinvestment Act of 2009 (Recovery Act) funds will be used to accelerate the civil construction activity as well as advance some major procurements in the project timeline. In FY 2009, the Recovery Act funds will be used to accelerate the ring building civil construction contract activities and several major infrastructure improvements that support the NSLS-II project.

In FY 2010, funds will be used to continue civil construction and advancing experimental and accelerator systems.

The project will be conducted in accordance with the project management requirements in DOE Order 413.3A, Program and Project Management for the Acquisition of Capital Assets.

### 5. Financial Schedule[a]

(dollars in thousands)

| | Appropriations | Obligations | Recovery Act Costs | Costs |
|---|---|---|---|---|
| Total Estimated Cost (TEC) | | | | |
| PED | | | | |
| FY 2007 | 3,000 | 3,000 | — | 2,292 |
| FY 2008 | 29,727 | 29,727 | — | 28,205 |
| FY 2009 | 27,273 | 27,273 | — | 27,508 |
| FY 2010 | — | — | — | 1,995 |
| Total, PED | 60,000 | 60,000 | — | 60,000 |
| Construction | | | | |
| FY 2009 | 66,000 | 66,000 | — | 52,211 |
| FY 2009 Recovery Act | 150,000 | 150,000 | 8,740 | — |
| FY 2010 | 139,000 | 139,000 | 114,198 | 49,000 |
| FY 2011 | 151,600 | 151,600 | 27,062 | 218,934 |
| FY 2012 | 151,400 | 151,400 | — | 166,343 |
| FY 2013 | 46,900 | 46,900 | — | 61,969 |
| FY 2014 | 26,300 | 26,300 | — | 27,255 |
| FY 2015 | — | — | — | 5,488 |
| Total, Construction | 731,200 | 731,200 | 150,000 | 581,200 |

[a] The costing profile is based on the current execution plan which does not reflect the impact of accelerated funding under the Recovery Act. The execution plan will be reevaluated during the upcoming year and the cost profile will be updated.

(dollars in thousands)

| | Appropriations | Obligations | Recovery Act Costs | Costs |
|---|---|---|---|---|
| TEC | | | | |
| FY 2007 | 3,000 | 3,000 | — | 2,292 |
| FY 2008 | 29,727 | 29,727 | — | 28,205 |
| FY 2009 | 93,273 | 93,273 | — | 79,719 |
| FY 2009 Recovery Act | 150,000 | 150,000 | 8,740 | — |
| FY 2010 | 139,000 | 139,000 | 114,198 | 50,995 |
| FY 2011 | 151,600 | 151,600 | 27,062 | 218,934 |
| FY 2012 | 151,400 | 151,400 | — | 166,343 |
| FY 2013 | 46,900 | 46,900 | — | 61,969 |
| FY 2014 | 26,300 | 26,300 | — | 27,255 |
| FY 2015 | — | — | — | 5,488 |
| Total, TEC | 791,200 | 791,200 | 150,000 | 641,200 |
| Other Project Cost (OPC) | | | | |
| OPC except D&D | | | | |
| FY 2005 | 1,000 | 1,000 | — | — |
| FY 2006 | 4,800 | 4,800 | — | 4,958 |
| FY 2007 | 22,000 | 22,000 | — | 20,461 |
| FY 2008 | 20,000 | 20,000 | — | 15,508 |
| FY 2009 | 10,000 | 10,000 | — | 10,773 |
| FY 2010 | 2,000 | 2,000 | — | 5,500 |
| FY 2011 | 1,500 | 1,500 | — | 4,100 |
| FY 2012 | 7,700 | 7,700 | — | 7,600 |
| FY 2013 | 24,400 | 24,400 | — | 24,500 |
| FY 2014 | 22,400 | 22,400 | — | 22,400 |
| FY 2015 | 5,000 | 5,000 | — | 5,000 |
| Total, OPC except D&D | 120,800 | 120,800 | | 120,800 |
| Total Project Cost (TPC) | | | | |
| FY 2005 | 1,000 | 1,000 | — | — |
| FY 2006 | 4,800 | 4,800 | — | 4,958 |
| FY 2007 | 25,000 | 25,000 | — | 22,753 |
| FY 2008 | 49,727 | 49,727 | — | 43,713 |
| FY 2009 | 103,273 | 103,273 | — | 90,492 |
| FY 2009 Recovery Act | 150,000 | 150,000 | 8,740 | — |
| FY 2010 | 141,000 | 141,000 | 114,198 | 56,495 |
| FY 2011 | 153,100 | 153,100 | 27,062 | 223,034 |
| FY 2012 | 159,100 | 159,100 | — | 173,943 |

| | (dollars in thousands) | | | |
|---|---|---|---|---|
| | Appropriations | Obligations | Recovery Act Costs | Costs |
| FY 2013 | 71,300 | 71,300 | — | 86,469 |
| FY 2014 | 48,700 | 48,700 | — | 49,655 |
| FY 2015 | 5,000 | 5,000 | — | 10,488 |
| Total, TPC | 912,000 | 912,000 | 150,000 | 762,000 |

## 6. Details of Project Cost Estimate

| | (dollars in thousands) | | |
|---|---|---|---|
| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
| Total Estimated Cost (TEC) | | | |
| Design (PED) | | | |
| Design | 60,000 | 49,000 | 49,000 |
| Contingency | — | 11,000 | 11,000 |
| Total, PED | 60,000 | 60,000 | 60,000 |
| Construction | | | |
| Site Preparation | 9,243 | 9,243 | 9,243 |
| Equipment | 32,078 | 31,579 | 31,579 |
| Other Construction | 518,635 | 518,381 | 518,381 |
| Contingency | 171,244 | 171,997 | 171,997 |
| Total, Construction | 731,200 | 731,200 | 731,200 |
| Total, TEC | 791,200 | 791,200 | 791,200 |
| Contingency, TEC | 171,244 | 182,997 | 182,997 |
| | | | |
| Other Project Cost (OPC) | | | |
| Conceptual Planning | 24,800 | 24,800 | 24,800 |
| Research and Development | 35,800 | 35,800 | 35,800 |
| Start-Up | 50,200 | 50,200 | 50,200 |
| Contingency | 10,000 | 10,000 | 10,000 |
| Total, OPC | 120,800 | 120,800 | 120,800 |
| Contingency, OPC | 10,000 | 10,000 | 10,000 |
| Total, TPC | 912,000 | 912,000 | 912,000 |
| Total, Contingency | 181,244 | 192,997 | 192,997 |

## 7. Schedule of Project Costs

For Schedule of project costs, see Section 5, “Financial Schedule.”

## 8. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Beneficial Occupancy of the Experimental Floor | 4Q FY 2012 |
| Expected Useful Life (number of years) | 25 |
| Expected Future start of D&D of this capital asset (fiscal quarter) | N/A |

### (Related Funding Requirements)

(dollars in thousands)

| | Annual Costs | | Life cycle costs | |
|---|---|---|---|---|
| | Current Estimate | Prior Estimate | Current Estimate | Prior Estimate |
| Operations | 119,400 | 119,400 | 4,470,000 | 4,470,000 |
| Maintenance | 21,100 | 21,100 | 789,000 | 789,000 |
| Total Operations and Maintenance | 140,500 | 140,500 | 5,259,000 | 5,259,000 |

## 9. Required D&D Information

| | Square Feet |
|---|---|
| Area of new construction | ~ 400,000 |
| Area of existing facilities being replaced | N/A |
| Area of any additional space that will require D&D to meet the "one-for-one" requirement | NA (see below) |

The existing facility (NSLS) will be converted to another use. The one-for-one replacement has been met through completed and planned elimination of space at Brookhaven National Laboratory (BNL) along with "banked" space at the Massachusetts Institute of Technology (MIT) in Middleton, MA, and at the East Tennessee Technology Park (ETTP) in Oak Ridge, TN. A waiver from the one-for-one requirement to eliminate excess space at Brookhaven to offset the NSLS-II project was approved by Secretary Bodman on April 20, 2007. The waiver identified approximately 460,000 square feet of banked excess facilities space that were eliminated in FY 2006 at MIT and ETTP.

## 10. Acquisition Approach (formerly Method of Performance)

The acquisition strategy selected relies on the BNL management and operating (M&O) contractor to directly manage the NSLS-II acquisition. The acquisition of large research facilities is within the scope of the DOE contract for the management and operation of BNL and consistent with the general expectation of the responsibilities of DOE M&O contractors.

The design, fabrication, assembly, installation, testing, and commissioning of the NSLS-II project will largely be performed by the BNL NSLS-II scientific and technical staff. Much of the subcontracted work to be performed for NSLS-II consists of hardware fabrication and conventional facilities construction. Each system or component will be procured using fixed price contracts, unless there is a compelling reason to employ another contract type. Best-value competitive procurements will be employed to the maximum extent possible.

Many major procurements will be either build-to-print, following BNL/NSLS-II drawings and specifications, or readily available off-the-shelf. Source selection will be carried out in accordance with

DOE-approved policies and procedures. Acquisition strategies will be chosen to obtain the best value based on the assessment of technical and cost risks on a case-by-case basis. For standard, build-to-print fabrications and the purchase of off-the-shelf equipment for routine applications, available purchasing techniques include price competition among technically qualified suppliers and use of competitively awarded blanket purchase agreements.

The architect-engineer (A-E) contract was placed on a firm-fixed-price basis for the Final (Title II) Design and (Title III) construction support services. The general construction contract will be placed on a firm-fixed-price basis. The design specifications are sufficiently detailed to allow prospective constructors to formulate firm-fixed-price offers without excessive contingency and allowances.

NSLS-II project management has identified major procurements that represent significant complexity or cost and schedule risk. Advance procurement plans (APPs) are being prepared for each major procurement. The APPs include discussion of contract type, special contracting methods, special clauses or deviations required, and lease or purchase decisions. These final APPs will identify critical procurement activities and help to mitigate or avoid schedule conflicts and other procurement-related problems. At appropriate dollar levels, the APPs are approved by the responsible Division Director, the NSLS-II Procurement Manager, the NSLS-II Deputy Director, and the NSLS-II Project Director.

**05-R-320, Linac Coherent Light Source,**
**Stanford Linear Accelerator Center, Menlo Park, California**
**Project Data Sheet is for Construction**

## 1. Significant Changes

The most recent DOE O413.3A Critical Decision (CD) is CD-3b (Approve Start of Construction), which was approved in March 2006 with a Total Project Cost of $379,000,000. A revised baseline was approved by the Deputy Secretary in January 2008 due to the impacts of the FY 2007 continuing resolution and funding shortfall. The revised baseline TPC is $420,000,000 and project completion is 4Q FY 2010.

A Federal Project Director with certification level III has been assigned to this project.

This Project Data Sheet (PDS) is an update of the FY 2009 PDS.

## 2. Design, Construction, and D&D Schedule

(fiscal quarter or date)

| | CD-0 | CD-1 | (Design/PED Complete) | CD-2a | CD-2b | CD-3a |
|---|---|---|---|---|---|---|
| FY 2003 | 06/13/2001 | 1Q FY 2003 | 2Q FY 2005 | N/A | N/A | N/A |
| FY 2004 | 06/13/2001 | 10/16/2002 | 4Q FY 2006 | 3Q FY 2003 | N/A | 1Q FY 2005 |
| FY 2005 | 06/13/2001 | 10/16/2002 | 4Q FY 2006 | 3Q FY 2003 | N/A | 1Q FY 2005 |
| FY 2006 | 06/13/2001 | 10/16/2002 | 4Q FY 2006 | 07/02/2003 | N/A | 1Q FY 2005 |
| FY 2007 | 06/13/2001 | 10/16/2002 | 4Q FY 2006 | 07/02/2003 | 04/11/2005 | 12/10/2004 |
| FY 2008 | 06/13/2001 | 10/16/2002 | 3Q FY 2008 | 07/02/2003 | 04/11/2005 | 12/10/2004 |
| FY 2009 | 06/13/2001 | 10/16/2002 | 2Q FY 2008 | 07/02/2003 | 04/11/2005 | 12/10/2004 |
| FY 2010 | 06/13/2001 | 10/16/2002 | 2Q FY 2008 | 07/02/2003 | 04/11/2005 | 12/10/2004 |

CD-0 – Approve Mission Need
CD-1 – Approve Alternative Selection and Cost Range
CD-2a – Approve Long-Lead Budget
CD-2b – Approve Performance Baseline
CD-3a – Approve Start of Long-Lead Procurements

(fiscal quarter or date)

| | CD-3b | CD-4 | D&D Start | D&D Complete | Performance Baseline Validation |
|---|---|---|---|---|---|
| FY 2003 | 1Q FY 2004 | 1Q FY 2007 | N/A | N/A | 3Q FY 2002 |
| FY 2004 | 1Q FY 2004 | 1Q FY 2007 | N/A | N./A | 3Q FY 2002 |
| FY 2005 | 1Q FY 2004 | 1Q FY 2007 | N/A | N/A | 3Q FY 2002 |
| FY 2006 | 1Q FY 2004 | 1Q FY 2007 | N/A | N/A | 3Q FY 2002 |
| FY 2007 | 2Q FY 2006 | 2Q FY 2009 | N/A | N/A | 1Q FY 2005 |
| FY 2008 | 2Q FY 2006 | 2Q FY 2009 | N/A | N/A | 1Q FY 2005 |

(fiscal quarter or date)

| | CD-3b | CD-4 | D&D Start | D&D Complete | Performance Baseline Validation |
|---|---|---|---|---|---|
| FY 2009 | 3/21/2006 | 4Q FY 2010[a] | N/A | N/A | 1Q FY 2008 |
| FY 2010 | 3/21/2006 | 4Q FY 2010 | N/A | N/A | 1Q FY 2008 |

CD-3b – Approve Start of Construction
CD-4 – Approve Construction Complete

## 3. Baseline and Validation Status

(dollars in thousands)

| | TEC, PED | TEC, Construction | TEC, Total | OPC Except D&D | OPC D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2003 | 33,500 | TBD | TBD | 1,500 | N/A | TBD | TBD |
| FY 2004 | 36,000 | TBD | TBD | 7,500 | N/A | TBD | TBD |
| FY 2005 | 36,000 | 279,000 | 315,000 | 64,000 | N/A | 64,000 | 379,000 |
| FY 2006 | 36,000 | 279,000 | 315,000 | 64,000 | N/A | 64,000 | 379,000 |
| FY 2007 | 35,974 | 279,026 | 315,000 | 64,000 | N/A | 64,000 | 379,000 |
| FY 2008 | 35,974 | 279,026 | 315,000 | 64,000 | N/A | 64,000 | 379,000 |
| FY 2009 | 35,974 | 316,026 | 352,000 | 68,000 | N/A | 68,000 | 420,000[b] |
| FY 2010 | 35,974 | 316,026 | 352,000 | 68,000 | N/A | 68,000 | 420,000 |

## 4. Project Description, Justification, and Scope

This project is being conducted in accordance with the project management requirements in DOE O 413.3A . Program and Project Management for the Acquisition of Capital Assets and all appropriate project management requirements have been met.

The purpose of the Linac Coherent Light Source (LCLS) project is to provide laser-like radiation in the x-ray region of the spectrum that is 10 billion times greater in peak brightness than any existing coherent x-ray light source. This advance in brightness is similar to that of a synchrotron over a 1960s laboratory x-ray tube. Synchrotrons revolutionized science across disciplines ranging from atomic physics to structural biology. Advances from the LCLS are expected to be equally dramatic. The LCLS project will provide the first demonstration of an x-ray free electron laser (FEL) in the 1.5–15 Angstrom range and will apply these extraordinary, high-brightness x-rays to an initial set of scientific problems described below. This will be the world's first such facility.

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[a] Due to the delay and reduced funding related to the FY 2007 Continuing Resolution, the project prepared a revised cost and schedule baseline. The revised baseline was validated by the Office of Engineering and Construction Management and the Deputy Secretary approved the revised baseline in January 2008. The approved baseline TPC is $420M and project completion (CD-4) is scheduled for 4Q FY 2010.

[b] The full project TEC and TPC, established at Critical Decision 2b (Approve Performance Baseline), were $315,000,000 and $379,000,000, respectively, and include the costs for PED from project 03-SC-002. Due to the delay and reduced funding related to the FY 2007 Continuing Resolution, the project prepared a revised cost and schedule baseline. The revised baseline was validated by the Office of Engineering and Construction Management and the Deputy Secretary approved the revised baseline in January 2008. The approved baseline TPC is $420,000,000 and project completion (CD-4) scheduled 4Q FY 2010.

The LCLS is based on the existing SLAC linac. The SLAC linac can accelerate electrons or positrons to 50 GeV for colliding beam experiments and for nuclear and high-energy physics experiments on fixed targets. For the LCLS, the linac will produce high-brightness 5-15 GeV electron bunches at a 120 Hertz repetition rate. When traveling through the new 120 meter long LCLS undulator, these electron bunches will amplify the emitted x-ray radiation to produce an intense, coherent x-ray beam for scientific research.

The LCLS makes use of technologies developed for SLAC and the next generation of linear colliders, as well as the progress in the production of intense electron beams with radiofrequency photocathode guns. These advances in the creation, compression, transport, and monitoring of bright electron beams make it possible to base this next generation of x-ray synchrotron radiation sources on linear accelerators rather than on storage rings.

The LCLS will have properties vastly exceeding those of current x-ray sources (both synchrotron radiation light sources and so-called table-top x-ray lasers) in three key areas: peak brightness, coherence (i.e., laser-like properties), and ultrashort pulses. The peak brightness of the LCLS is 10 billion times greater than current synchrotrons, providing $10^{11}$ x-ray photons in a pulse with duration of less than 230 femtoseconds. These characteristics of the LCLS will open new realms of scientific application in the chemical, material, and biological sciences.

The LCLS project requires a 135 MeV injector built at Sector 20 of the 30-sector SLAC linac to create the electron beam required for the x-ray FEL. The last one-third of the linac was modified by adding two magnetic bunch compressors. Most of the linac and its infrastructure will remain unchanged. The existing components in the final focus test beam tunnel were removed and replaced by a new beam transfer hall and undulator tunnel with associated equipment. Two new buildings, the Near Experimental Hall and the Far Experimental Hall, were constructed and connected by the x-ray beam line tunnel. The civil construction bids were much higher than the baseline estimates. As a result, the conventional facilities scope will not include the planned Central Laboratory Office Complex. Instead, existing buildings at SLAC will be renovated or a smaller scale office building will be constructed to fulfill the office space requirements. There are no impacts to the project’s capabilities and key technical operating parameters.

The combined characteristics (spectral content, peak power, pulse duration, and coherence) of the LCLS beam are far beyond those of existing light sources. The demands placed on the x-ray instrumentation and optics required for scientific experiments with the LCLS are unprecedented. The LCLS experimental program will commence with: measurements of the x-ray beam characteristics and tests of the capabilities of x-ray optics, instrumentation, and techniques required for full exploitation of the scientific potential of the facility. For this reason, the project scope includes a comprehensive suite of instrumentation for characterization of the x-ray beam and for early experiments in atomic, molecular, and optical physics. The experiments include x-ray multiphoton processes with isolated atoms, simple molecules, and clusters. Also included in the scope of the LCLS project are the instrumentation and infrastructure necessary to support research at the LCLS, such as experiment hutches and associated interlock systems, computers for data collection and data analysis, devices for attenuation and collimation of the x-ray beam, prototype optics for manipulation of the intense x-ray beam, and synchronized pump lasers.

Beyond the scope of the LCLS construction project, an instrument development program has been implemented in order to qualify and provide instruments for the LCLS. The key element of this program is a major item of equipment (MIE)—the LCLS Ultrafast Science Instruments (LUSI) project. These instruments will all be delivered after completion of the LCLS line item construction project. The LCLS

Scientific Advisory Committee, working in coordination with the broad scientific community, has already identified a number of high priority initial experiments that are summarized in the document, *LCLS: The First Experiments*. Five specific areas of experimentation are: fundamental studies of the interaction of intense x-ray pulses with simple atomic systems, use of LCLS to create warm dense matter and plasmas, structural studies on single nanoscale particles and biomolecules, ultrafast dynamics in chemistry and solid-state physics, and studies of nanoscale structure and dynamics in condensed matter. The combination of extreme brightness and short pulse length will make it possible to follow dynamical processes in chemistry and condensed matter physics in real time. It may also enable the determination of the structure of single biomolecules or small nanocrystals using only the diffraction pattern from a single moiety. This application has great potential in structural biology, particularly for important systems such as membrane proteins, which are virtually uncharacterized by x-ray crystallography because they are nearly impossible to crystallize. Instrument teams will form to propose instruments to address these and other scientific areas of inquiry.

Construction funding provided in FY 2006 was for starting physical construction of the LCLS conventional facilities including ground-breaking for the LCLS Near Experimental Hall, Undulator Hall, Beam Transfer Hall, and connecting beam transfer tunnels. In addition, the injector was completed and construction of the downstream linac and electron beam transport to the undulator hall began. Undulator module assembly was started along with construction of x-ray transport/optics/diagnostics systems.

The FY 2007 funding was for continuation of construction of the LCLS conventional facilities including the LCLS Near Experimental Hall, Undulator Hall, Beam Transfer Hall, connecting beam transfer tunnels, and Far Experimental Hall. In addition, the assembly and delivery of the undulators and undulator infrastructure to SLAC’s Magnetic Measurement Facility is planned, as well as the procurements for the x-ray optics, diagnostics, and end stations. Delivery of the undulators in FY 2007 enables achievement of performance goals in FY 2010.

Construction funding in FY 2008 was for continuation of most of the LCLS conventional facilities and for continued procurement and installation of the technical hardware. The FY 2009 funding was for undulator and photon diagnostics installations, experimental halls installations, renovation of existing buildings at SLAC to provide office space in support of LCLS operations, and installation of technical hardware for x-ray transport system. FY 2010 funding supports data storage/switches, network fibers, commissioning support, project office support of project closeout (CD-4), and spares.

## 5. Financial Schedule[a]

(dollars in thousands)

| | Appropriations | Obligations | Costs |
|---|---|---|---|
| Total Estimated Cost (TEC)[b] | | | |
| PED | | | |
| FY 2003 | 5,925 | 5,925 | 3,644 |
| FY 2004 | 7,456 | 7,456 | 9,713 |
| FY 2005 | 19,914 | 19,914 | 16,805 |
| FY 2006 | 2,518 | 2,518 | 5,066 |
| FY 2007 | 161 | 161 | 725 |
| FY 2008 | — | — | 1 |
| FY 2009 | — | — | 20 |
| Total, PED (PED no. 03-SC-002) | 35,974 | 35,974 | 35,974 |
| | | | |
| Construction[a] | | | |
| FY 2005 | 29,760 | 29,760 | 7,868 |
| FY 2006 | 82,170 | 82,170 | 61,395 |
| FY 2007 | 101,000 | 101,000 | 99,148 |
| FY 2008 | 50,889 | 50,889 | 88,247 |
| FY 2009 | 36,967 | 36,967 | 38,605 |
| FY 2010 | 15,240 | 15,240 | 20,763 |
| Total, Construction | 316,026 | 316,026 | 316,026 |
| | | | |
| TEC | | | |
| FY 2003 | 5,925 | 5,925 | 3,644 |
| FY 2004 | 7,456 | 7,456 | 9,713 |

[a] The full project TEC and TPC, established at Critical Decision 2b (Approve Performance Baseline), were $315,000,000 and $379,000,000, respectively, and include the costs for PED from project 03-SC-002. Due to the delay and reduced funding related to the FY 2007 Continuing Resolution, the project prepared a revised cost and schedule baseline. The revised baseline was validated by the Office of Engineering and Construction Management and the Deputy Secretary approved the revised baseline in January 2008. The approved baseline TPC is $420M and project completion (CD-4) is scheduled for 4Q FY 2010.

[b] PED funding was reduced by $75,000 as a result of the FY 2003 general reduction and rescission, by $44,000 as a result of the FY 2004 rescission, by $161,000 as a result of the FY 2005 rescission, and by $26,000 as a result of the FY 2006 rescission. This total reduction was restored in FY 2005, FY 2006, and FY 2007 to maintain the TEC and project scope.

[a] FY 2005 funding was for long-lead procurements. The scope of work in FY 2005 was expanded to include modification of existing facilities at the Stanford Linear Accelerator Center for testing of the long-lead equipment items. Construction funding was reduced by $240,000 as a result of the FY 2005 rescission and by $830,000 as a result of the FY 2006 rescission. This total reduction is restored in FY 2007 and FY 2008 to maintain the TEC and project scope. Construction funding was reduced by $4,740,000 in FY 2007 as the result of a budget reduction. Construction funding was reduced by $437,340 in FY 2008 as a result of the general rescission. Funding reduction will be restored in FY 2009 to maintain project schedule.

| | (dollars in thousands) | | |
|---|---|---|---|
| | Appropriations | Obligations | Costs |
| FY 2005 | 49,674 | 49,674 | 24,673 |
| FY 2006 | 84,688 | 84,688 | 66,461 |
| FY 2007 | 101,161 | 101,161 | 99,873 |
| FY 2008 | 50,889 | 50,889 | 88,248 |
| FY 2009 | 36,967 | 36,967 | 38,625 |
| FY 2010 | 15,240 | 15,240 | 20,763 |
| Total, TEC | 352,000 | 352,000 | 352,000 |
| | | | |
| Other Project Cost (OPC)[a] | | | |
| OPC except D&D | | | |
| FY 2002 | 1,500 | 1,500 | 1,500 |
| FY 2003 | — | — | — |
| FY 2004 | 2,000 | 2,000 | 1,991 |
| FY 2005 | 4,000 | 4,000 | 3,131 |
| FY 2006 | 3,500 | 3,500 | 2,461 |
| FY 2007 | 13,000 | 13,000 | 12,461 |
| FY 2008 | 15,500 | 15,500 | 16,315 |
| FY 2009 | 17,000 | 17,000 | 18,385 |
| FY 2010 | 11,500 | 11,500 | 11,756 |
| Total, OPC | 68,000 | 68,000 | 68,000 |
| | | | |
| Total Project Cost (TPC) | | | |
| FY 2002 | 1,500 | 1,500 | 1,500 |
| FY 2003 | 5,925 | 5,925 | 3,644 |
| FY 2004 | 9,456 | 9,456 | 11,704 |
| FY 2005 | 53,674 | 53,674 | 27,804 |
| FY 2006 | 88,188 | 88,188 | 68,922 |
| FY 2007 | 114,161 | 114,161 | 112,334 |
| FY 2008 | 66,389 | 66,389 | 104,563 |
| FY 2009 | 53,967 | 53,967 | 57,010 |
| FY 2010 | 26,740 | 26,740 | 32,519 |
| Total, TPC | 420,000 | 420,000 | 420,000 |

[a] OPC funding was reduced by $3,000,000 in FY 2007 as the result of a budget reduction.

## 6. Details of Project Cost Estimate[a]

| | (dollars in thousands) | | |
|---|---|---|---|
| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
| Total Estimated Cost (TEC) | | | |
| Design (PED) (PED no. 03-SC-002) | | | |
| Design | 35,974 | 35,974 | 35,974 |
| Construction | | | |
| Site Preparation | 9,000 | 9,000 | 9,000 |
| Equipment | 122,052 | 122,052 | 110,652 |
| Other Construction | 154,976 | 152,834 | 93,400 |
| Contingency | 29,998 | 32,140 | 65,974 |
| Total, Construction | 316,026 | 316,026 | 279,026 |
| Total, TEC | 352,000 | 352,000 | 315,000 |
| Contingency, TEC | 29,998 | 32,140 | 65,974 |
| | | | |
| Other Project Cost (OPC) | | | |
| OPC, except D&D | | | |
| Conceptual Planning[a] | 7,700 | 7,700 | 7,700 |
| Start-up[b] | 53,811 | 52,300 | 50,324 |
| Contingency | 6,489 | 8,000 | 5,976 |
| Total, OPC | 68,000 | 68,000 | 64,000 |
| Contingency, OPC | 6,489 | 8,000 | 5,976 |
| Total, TPC | 420,000 | 420,000 | 379,000 |
| Total, Contingency | 36,487 | 40,140 | 71,950 |

## 7. Schedule of Project Costs

For schedule of project costs, see Section 5, "Financial Schedule."

[a] The full project TEC and TPC, established at Critical Decision 2b (Approve Performance Baseline), were $315,000,000 and $379,000,000, respectively, and include the costs for PED from project 03-SC-002. Due to the delay and reduced funding related to the FY 2007 Continuing Resolution, the project prepared a revised cost and schedule baseline. The revised baseline was validated by the Office of Engineering and Construction Management and the Deputy Secretary approved the revised baseline in January 2008. The approved baseline TPC is $420,000,000 and project completion (CD-4) scheduled 4Q FY 2010.

[a] Costs in this category include NEPA, conceptual design, and R&D.

[b] Costs in this category include start-up (pre-operations) and spares.

## 8. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Full Operations or Beneficial Occupancy (fiscal quarter or date) | 4Q FY 2010 |
| Expected Useful Life (number of years) | 30 |
| Expected Future start of D&D of this capital asset (fiscal year) | FY 2041[a] |

### (Related Funding Requirements)

(dollars in thousands)

| | Annual Costs | | Life cycle costs | |
|---|---|---|---|---|
| | Current Total Estimate[b] | Previous Total Estimate | Current Total Estimate[c] | Previous Total Estimate |
| Operations | 12,500 | 12,500 | 684,328 | 684,328 |
| Maintenance | 12,500 | 12,500 | 684,328 | 684,328 |
| Total, Operations & Maintenance | 25,000 | 25,000 | 1,368,656 | 1,368,656 |

FY 2011 is expected to be the first full year of LCLS facility operations. The current estimate is preliminary and based on historical experience with operating similar types and sizes of facilities. This estimate will be refined as the LCLS project approaches completion.

The estimate includes LCLS facility operations only. It does not include operation of the SLAC linac which was funded by HEP in FY 2005 and prior years, but began transitioning to BES funding in FY 2006 and is fully funded by BES in FY 2009. Operation of the SLAC Linac is essential to the operation of the LCLS.

## 9. Required D&D Information

LCLS is an existing project and construction funding was requested in FY 2005. The replacement of existing facilities and the one-for-one requirements have been complied with (ref. FY 2009 OMB Budget Call, Attachment H Project Data Sheet Guidance, Page H-7).

## 10. Acquisition Approach

A Conceptual Design Report (CDR) for the project was completed and reviewed. Key design activities were specified in the areas of the injector, undulator, x-ray optics, and experimental halls to reduce schedule risk to the project and expedite the startup. Also, the LCLS management systems were put in place and tested during the Project Engineering and Design (PED) phase. These activities are managed by the LCLS Project Office at SLAC, with additional portions of the project being executed by staff at Argonne National Laboratory (ANL) and Lawrence Livermore National Laboratory (LLNL).

The design of technical systems is being accomplished by the three collaborating laboratories. The conventional construction design aspect was contracted to an experienced architect-engineer (A-E) firm to perform Title I and II design. Title I design was completed in FY 2004. Title II design began in

[a] Assumption: No major upgrades to expand or extend LCLS capabilities and operational cycle will be implemented.

[b] LCLS is currently under construction and operation is expected to begin in FY 2010. The Annual Cost estimate shown in the table above is for a full year of operation.

[c] The life cycle cost estimate includes operations and maintenance annual costs escalated through the LCLS facility expected useful life of 30 years, in accordance with the DOE budget guidance. The cost estimate does not include D&D of the LCLS facility after useful life. The project has better defined operational and maintenance (O&M) needs for the experimental facilities as it approaches Critical Design 4. The cost estimates for O&M are updated annually.

FY 2005 and was completed in FY 2006. An experienced Construction Manager/General Contractor is under contract to carry out conventional facilities construction which achieved beneficial occupancy in November 2008.

# Advanced Scientific Computing Research

## Funding Profile by Subprogram

(dollars in thousands)

| | FY 2008 Current Appropriation | FY 2009 Original Appropriation | FY 2009 Additional Appropriation[a] | FY 2010 Request |
|---|---|---|---|---|
| Advanced Scientific Computing Research | | | | |
| Mathematical, Computational, and Computer Sciences Research | 117,900 | 144,205 | +37,130 | 163,792 |
| High Performance Computing and Network Facilities | 223,874 | 224,615 | +119,980 | 245,208 |
| Total, Advanced Scientific Computing Research | 341,774[b] | 368,820 | +157,110 | 409,000 |

**Public Law Authorizations:**
Public Law 95–91, "Department of Energy Organization Act", 1977
Public Law 108–423, "Department of Energy High-End Computing Revitalization Act of 2004"
Public Law 109–58, "Energy Policy Act of 2005"
Public Law 110–69, "America COMPETES Act of 2007"

## Program Overview

### Mission

The mission of the Advanced Scientific Computing Research (ASCR) program is to discover, develop, and deploy computational and networking capabilities to analyze, model, simulate, and predict complex phenomena important to the Department of Energy. A particular challenge of this program is fulfilling the science potential of emerging multi-core computing systems and other novel "extreme-scale" computing architectures, which will require significant modifications to today's tools and techniques.

### Background

Imagine exploring the inner workings of a supernova or traveling backward and forward in time to observe changes in our global climate. Scientists today are able to explore these realms thanks to a 100 fold increase in computing power delivered over the past five years and to the software developed to harness the power of these forefront computers.

Throughout recorded history, humankind has always been interested in understanding the mysteries of the universe. Mathematics has been the primary tool. Pythagoras used mathematics to determine the diameter of the earth. Newton and Leibniz invented calculus to understand the movement of the planets. Mathematical research in the 1800s led to Einstein's Theory of General Relativity.

While mathematics enabled the study of increasingly complex problems, the time to carry out these calculations became unmanageable. Today, advances in mathematics and computing enable scientists to understand everything from Alzheimer's disease to climate change. ASCR and its predecessor organizations have led these advances for the past thirty years.

[a] The Additional Appropriation column reflects the planned allocation of funding from the American Recovery and Reinvestment Act of 2009, P.L. 111–5. See the Department of Energy Recover website at http://www.energy.gov/recovery for up-to-date information regarding Recovery Act Funding.
[b] Total is reduced by $9,399,000: $8,392,000 of which was transferred to the Small Business Innovative Research (SBIR) program and $1,007,000 of which was transferred to the Small Business Technology Transfer (STTR) program.

In past year, ASCR has delivered petascale computing power to the open science community and two of the world's fastest computers for open-science. These machines enabled two Gordon Bell prizes, including the world's first petascale application, and swept the High Performance Computing challenge at SuperComputing08. Since the machines are open to all on a competitive basis, the scientific applications that are running provide new insights into areas such as: first-principles flame simulation to guide design of fuel-efficient clean engines, high temperature superconductivity, the molecular basis for Parkinson's disease, supernova shock wave instability, designing proteins at atomic scale and creating enzymes.

This growing area of research allows scientists to see things that can't be seen experimentally and to reveal new insights from experimental data. Computational scientists create mathematical models and simulations of physical, biological and chemical phenomena, which allow them to better understand the phenomena and to predict behavior. In the case of climate change, we cannot afford to simply wait and record the impacts of increasing concentrations of greenhouse gases. Through computation, scientists can model what is known about the Earth system and identify experiments to gather necessary data to further refine the model. The model allows us to predict, with increasing confidence, future changes in the climate and identity mitigation strategies for policy makers. Such research has made computational science a true third pillar of science, alongside theory and experiment.

ASCR supports basic research in both applied mathematics and computer science focused in areas relevant to high performance computing. It links this research to scientists across SC through the Scientific Discovery through Advanced Computing (SciDAC) program. SciDAC facilitates transfer of the results of basic efforts into computational science through direct partnerships between applied mathematicians, computer scientists and domain experts in a specific discipline. These partnerships have been spectacularly successful with documented improvements in code performance in excess of 10,000 percent.

The other primary goal of the ASCR program is to remove geography as a barrier to science. Even before the Internet, researchers across the Office of Science have been communicating with each other, exchanging large data sets and running complex calculations and experiments in remote scientific user facilities. ASCR has had a leading role in driving development of the networks connecting these researchers. Even today, the invisible glue that binds all the networks in the world together and effortlessly passes billions of searches and trillions of bits has roots in ASCR research. ASCR researchers helped to establish critical protocols such as TCP/IP on which the current Internet is based. ASCR advanced networking research also makes international collaborations, such as the Large Hadron Collider and ITER, possible. The Internet has removed barriers between people and ASCR's advanced scientific networks have removed barriers between scientists and research facilities.

Looking forward, ASCR must continue to take its computers and networks to the leading edge of technology and transform them into tools for scientific discovery. Therefore, ASCR must address the emerging challenges of next generation computing systems and transforming extreme scale data into knowledge. The ASCR approach of integrating research results across disciples and with forefront facilities has been the key to our history of success in computational science. With this integrated approach ASCR will continue to deliver scientific insight to address national problems.

### Strategic and GPRA Unit Program Goals

The ASCR program has one Government Performance and Results Act (GPRA) Unit Program Goal which contributes to Strategic Goals 3.1 and 3.2 in the "goal cascade":

- GPRA Unit Program Goal 3.1/2.51.00: Deliver forefront computational and networking capabilities—Deliver forefront computational and networking capabilities to scientists nationwide that enable them to extend the frontiers of science, answering critical questions that range from the function of living cells to the power of fusion energy.

**Contribution to GPRA Unit Program Goal 3.1/2.51.00, Deliver forefront computational and networking capabilities**

ASCR contributes to this goal by delivering the fundamental mathematical and computer science research that enables the simulation and prediction of complex physical and biological systems, providing the advanced computing capabilities needed by researchers to take advantage of this understanding, and delivering the fundamental networking research and facilities that link scientists across the nation to both facilities and colleagues to enable scientific discovery.

ASCR supports fundamental research in applied mathematics, computer science, networking research, and tools for electronic collaboration; integrates the results of these basic research efforts into tools and software that can be used by scientists in other disciplines, especially through efforts such as SciDAC; and provides the advanced computing and network resources that enable scientists to use these tools for scientific inquiry. Applied mathematics enables scientists to accurately model physical and natural systems, and provides the algorithms the computer requires to manipulate that representation of the world effectively, exposing the underlying structure. Computer science research provides the link between the mathematics and the actual computer systems. Finally, scientific discovery results from simulations conducted on the advanced computers themselves, including experimental computers with hardware designs optimized to enable particular types of scientific applications, and the largest computing capabilities available to the general scientific community. All of these elements advance the frontiers of simulation and scientific discovery. Shrinking the distance between scientists and the resources they need is also critical to SC. The challenges that SC faces require teams of scientists distributed across the country, as well as the full national portfolio of experimental and computational tools. High performance networks and networking research provide the capability to move the millions of gigabytes that these resources generate to the scientists' desktops. Therefore, the ASCR program contributes to research programs across SC, as well as other elements of the Department.

The following indicators establish specific long term (ten year) goals in Scientific Advancement that the ASCR program is committed to, and progress can be measured against. The Advanced Scientific Computing Advisory Committee (ASCAC) was charged to review progress toward these long term measures and reported "good to excellent" progress to the Department in November, 2006. The long term measures are:

- Develop multiscale mathematics, numerical algorithms, and software that enable more effective models of systems such as the earth's climate, the behavior of materials, or the behavior of living cells that involve the interaction of complex processes taking place on vastly different time and/or length scales; and
- Develop, through the Genomics: GTL partnership with the Biological and Environmental Research (BER) program, the computational science capability to model a complete microbe and a simple microbial community. This capability will provide the science base to enable the development of novel clean-up technologies, bio-energy sources, and technologies for carbon sequestration.

## Annual Performance Results and Targets

| FY 2005 Results | FY 2006 Results | FY 2007 Results | FY 2008 Results | FY 2009 Targets | FY 2010 Targets |
|---|---|---|---|---|---|
| GPRA Unit Program Goal 3.1/2.51.00 (Deliver Forefront Computational and Networking Capabilities) | | | | | |
| Mathematical, Computational, and Computer Sciences Research | | | | | |
| Improved Computational Science Capabilities. Average annual percentage increased in the computational effectiveness (either by simulating the same problem in less time or simulating a larger problem in the same time) of a subset of application codes within the SciDAC effort. [Goal Met] | Improved Computational Science Capabilities. Average annual percentage increased in the computational effectiveness (either by simulating the same problem in less time or simulating a larger problem in the same time) of a subset of application codes within the SciDAC effort. FY 2006—>50%. [Goal Met] | Improved Computational Science Capabilities. Average annual percentage increased in the computational effectiveness (either by simulating the same problem in less time or simulating a larger problem in the same time) of a subset of application codes within the SciDAC effort. FY 2007—>100% [Goal Met] | Improve Computational Science Capabilities. Average annual percentage increase in the computational effectiveness (either by simulating the same problem in less time or simulating a larger problem in the same time) of a subset of application codes. FY 2008—>100% [Goal Met] | Improve Computational Science Capabilities. Average annual percentage increase in the computational effectiveness (either by simulating the same problem in less time or simulating a larger problem in the same time) of a subset of application codes. FY 2009—>100% | Improve Computational Science Capabilities. Average annual percentage increase in the computational effectiveness (either by simulating the same problem in less time or simulating a larger problem in the same time) of a subset of application codes, tools or libraries. FY 2010—>100% |
| High Performance Computing and Network Facilities | | | | | |
| Maintained Procurement Baselines. Percentages within (1) original baseline cost for completed procurements of major computer systems or network services, and (2) original performance baseline versus integrated performance over the life of the contracts. [Goal Met] | | | | | |
| Focused usage of the primary supercomputer at the NERSC on capability computing. Percentage of the computing time used that was accounted for by computations that require at least 1/8 of the total resource. [Goal Met] | Focused usage of the primary supercomputer at the NERSC on capability computing. Percentage of the computing time used that was accounted for by computations that require at least 1/8 of the total resource. FY 2006—40%. [Goal Met] | Focused usage of the primary supercomputer at the NERSC on capability computing. Percentage of the computing time used that was accounted for by computations that require at least 1/8 (760 processors) of the total resource. FY 2007—40% [Goal Met] | Focus usage of the primary supercomputer at the National Energy Research Scientific Computing Center (NERSC) on capability computing. Thirty percent (30%) of the computing time will be used by computations that require at least 1/8 (2,040 processors) of the NERSC resource. FY 2008 goal 30%. [Goal Met] | Focus usage of the primary supercomputer at the National Energy Research Scientific Computing Center (NERSC) on capability computing. Thirty percent (30%) of the computing time will be used by computations that require at least 1/8 (2,040 processors) of the NERSC resource. FY 2009 goal 30%. | Focus usage of the primary supercomputer at the National Energy Research Scientific Computing Center (NERSC) on capability computing. Forty percent (40%) of the computing time will be used by computations that require at least 1/8 (2,040 processors) of the NERSC resource. FY 2010 goal 40%. |

## Subprograms

To accomplish its mission and address the challenges described above, the ASCR program is organized into two subprograms—Mathematical, Computational, and Computer Sciences Research and High Performance Computing and Network Facilities.

- The *Mathematical, Computational, and Computer Sciences Research* subprogram develops mathematical descriptions, models, methods, and algorithms to describe and understand complex systems, often involving processes that span a wide range of time and/or length scales. Examples include the behavior of the earth's climate, living cells, and the reactive transport of contaminants through groundwater. The subprogram also develops the software to make effective use of advanced networks and computers, many of which contain thousands of multi-core processors with complicated interconnections, and to transform enormous data sets from experiments and simulations into scientific insight. In addition, the subprogram supports computational science partnerships within the Office of Science, R&D integration efforts with the Department's applied programs, and interagency collaborations.
- The *High Performance Computing and Network Facilities* subprogram delivers forefront computational and networking capabilities and contributes to the development of next-generation capabilities through support of prototypes and testbeds.

Effective scientific utilization of high-end capability computing requires dynamic partnerships among application scientists, applied mathematics, computer scientists and facility support staff. Therefore, close coordination both within and across ASCR subprograms and with partner organizations is key to the success of the ASCR program.

## Benefits

Computer-based simulation enables us to model the behavior of complex systems that are beyond the reach of experiment or for which there is no theory. Because computer-based simulation is so important to research programs across the Office of Science and throughout the government, the ASCR Leadership Computing Facilities are operated as open user facilities, with access determined by merit evaluation of proposals.

Many of the applications running on these facilities have direct benefit to science and society at large.

- Computational chemistry and simulation of nanomaterials is relevant to energy applications. These applications are funded in partnership with Basic Energy Sciences.
- The next generation Earth System Models will dramatically improve our ability to predict changes in global climate. This work is funded in partnership with Biological and Environmental Research. ASCR also provides the majority of the computing and networking resources for the U.S. contributions to the Intergovernmental Panel on Climate Change.
- Simulations of fusion reactors help to develop fusion as a clean, abundant energy source. This work is jointly funded with the Office of Fusion Energy Sciences.
- Computer modeling of nuclear structure has relevance for science, nuclear energy, and nuclear weapons. These applications are through partnerships with both Nuclear Physics and the National Nuclear Security Administration (NNSA).
- Understanding the mysteries of the universe is the focus of partnerships with High Energy Physics that include experiments, such as three dimensional simulations of supernovae events, which are only possible with leadership computing resources.

- Computational biology is relevant for energy and bioremediation applications. This work is a partnership with the Biological and Environmental Research Office. Projects from other agencies have investigated proteins; blood flow, and Parkinson's disease.
- Subsurface science research characterizes and predicts changes in the Department's environmental management sites. This work also has implications for the Department's efforts in subsurface carbon sequestration. These applications are partnerships with the Biological and Environmental Research.

Establishing leadership computing for the Office of Science required partnering with the hardware vendors to develop the software necessary to effectively use these powerful systems. These partnerships benefit many sectors of the economy from high-tech industry and academic research to software development and engineering.

Finally, ASCR's support of researchers and students (the next generation of researchers) is a benefit to the national research and development workforce.

**Program Planning and Management**

The ASCR program has developed a system of planning and priority setting that relies heavily on input from groups of outside experts. ASCR has also instituted a number of peer review and oversight processes designed to assess the quality, relevance, and performance of the ASCR portfolio on a regular basis. ASCR peer reviews all of its activities. One way in which ASCR ensures the integrity and effectiveness of the peer review processes is through the Advanced Scientific Computing Advisory Committee (ASCAC), which organizes regular Committees of Visitors to review ASCR research management, reviews output of the ASCR scientific user facilities, and reviews progress toward the long-term goals of the program. In addition, ASCAC identifies scientific challenges and opportunities, including specific bottlenecks to progress in areas such as climate change or computational biology, and comments on the overall balance of the ASCR portfolio.

In addition to ASCAC, critical tools for managing the ASCR scientific user facilities are annual operational reviews and requirements workshops. For example, ESnet conducts two network requirements workshops per year with individual DOE Office of Science program offices. The purpose of each workshop is to accurately characterize the near-term, medium-term and long-term network requirements of the science conducted by each program office. Since two workshops are conducted per year, ASCR refreshes the network requirements information for each of the six program offices every three years.

Community driven workshops are another critical means by which dialogues are facilitated and new research opportunities are identified. For example, ASCR is sponsoring a series of workshops in 2009, in partnership with the other Office of Science programs and the NNSA, to identify key science challenges in the disciplines important to the Department and the potential role of extreme scale computing in addressing those challenges.

Another important planning and coordination mechanism for ASCR is the National Science and Technology Council's (NSTC) subcommittee on Networking and Information Technology Research and Development (NITRD). ASCR is a major participant in the NITRD Program[a] which coordinates Federal research investments by the 11 member agencies in advanced information technologies such as computing, networking, and software through interagency working groups and coordinating groups. ASCR is a major participant and/or chair of the High End Computing Research and Development, Large Scale Networking, and High End Computing Infrastructure and Applications groups. In FY 2008, a

[a] Information on the NITRD Program can be found at http://www.nitrd.gov.

NITRD interagency working group, led by ASCR, the Department of Defense and the National Science Foundation, developed the "Federal Plan for Advanced Networking Research and Development"[a] to identify key research areas necessary to deliver future networking technologies that are critical for science but also for U.S. economic and national security. This interagency plan provides the framework in which ASCR research will address key issues for science and effectively leverage the research efforts of other agencies.

In October 2008, the National Research Council published a study titled "The Potential Impact of High-End Capability Computing (HECC) on Four Illustrative Fields of Science and Engineering"[b] that identifies and categorizes important scientific questions and technology problems for which an extraordinary advancement in our understanding is difficult or impossible without leading edge scientific simulation capabilities. In all four fields studied—atmospheric sciences, astrophysics, separations chemistry, and evolutionary biology—the committee found continuing demand for more powerful HECC and for large scale data management. The report outlined the major scientific challenges in the four fields and estimated the associated challenges in mathematics, computer science, and computing infrastructure. The conclusions of the report underscore the importance of balancing investments in high potential application areas, the high-end computing resources required by multiple fields, and the longer-term mathematics and computer science research that underpins continued progress. However, the report also emphasizes the added importance of linking these efforts: "In many cases HECC capabilities must continue to be advanced to maximize the value of data already collected…The committee foresees a growing need for computational scientists and engineers who can work with mathematicians and computer scientists to develop next-generation code."[c]

**Basic and Applied R&D Coordination**

A cornerstone of the ASCR program is coordination across disciples and programs. Partnerships within the Office of Science are mature and continue to advance use of high performance computing and scientific networks for science. In addition, ASCR continues to have a strong partnership with NNSA in areas of mutual interest including best practices for management of high performance computing facilities. Through NITRD, ASCR coordinates with similar programs across the federal government and directly partners with the Department of Defense on developing High Productivity Computing Systems and software and with the National Science Foundation on the Open Science Grid.

In discussions with the applied R&D programs in the Department, a key area of mutual interest continues to be in applied mathematics for optimization of complex systems, control theory, and risk assessment. This was the subject of an ASCR workshop held in December 2006 that identified research challenges in advanced mathematics that could benefit the optimization of fossil fuel power generation, the nuclear fuel lifecycle, and power grid control. Such research could increase the likelihood for success in DOE strategic initiatives such as smart grid. Another workshop, specifically focused on the challenges of grid modernization efforts, was organized in partnership with the Office of Electricity Delivery and Energy Reliability in March 2009. This workshop is part of a series of workshops on basic research needs in applied R&D areas. Other workshops have covered advanced nuclear energy systems (with the Office of Nuclear Energy), subsurface science (with the Office of Environmental Management, the Office of Fossil Energy, and the Office of Civilian Radioactive Waste Management), cyber security

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[a] The "Federal Plan for Advanced Networking Research and Development" can be found at http://www.nitrd.gov/Pubs/ITFAN-FINAL.pdf

[b] The "The Potential Impact of High-End Capability Computing (HECC) on Four Illustrative Fields of Science and Engineering" can be founds at http://www.nap.edu/catalog.php?record_id=12451

[c] "The Potential Impact of High-End Capability Computing (HECC) on Four Illustrative Fields of Science and Engineering", page 7–8

(with the Office of Electricity Delivery and Energy Reliability), and alternative and renewable energy (with the Office of Energy Efficiency and Renewable Energy). These workshops facilitate a dialogue between the ASCR research community and a specific applied R&D research community and identify opportunities for new research. This research becomes part of the ASCR program through investigator driven research proposals and is coordinated with the applied efforts through program manager interactions and joint principal investigator meetings.

**Budget Overview**

The FY 2010 ASCR budget request capitalizes on the significant gains in computational science over the past decade and positions the Department to attack scientific challenges through modeling and simulation in the next decade. The request also balances investments in high performance computing facilities and advanced networks with investments in applied mathematics, computer science, next generation networks for science and computational partnerships. This balance ensures continued progress in a wide array of fields important to the Department's missions for FY 2010 and for years to come.

The FY 2010 budget request continues support for the Leadership Computing Facility (LCF) at Oak Ridge National Laboratory (OLCF)—the most capable machine in the U.S. for open science, a 1.64 petaflop, multicore Cray Baker system—and will make that system openly available to the scientific community through the Innovative and Novel Computational Impact on Theory and Experiment (INCITE) program. In addition to INCITE projects, the OLCF will continue to provide access and assistance to tool and library developers and to researchers seeking to scale their application to this new realm of computing power. These activities are critical to harnessing the complexity of this architecture and to respond to the challenges associated with high performance computer systems with large numbers of multicore processors. This effort is also expected to build experience and tools for the synergistic DARPA High Productivity Computing Systems award to Cray, supported in part through the Research and Evaluation Prototypes activity, and other anticipated architectures that will exhibit even greater complexity.

The Argonne LCF (ALCF) will continue allocating the 556 teraflop IBM Blue Gene/P through INCITE in FY 2010. The FY 2010 budget request also includes site preparation activities for a next generation machine such as the one being developed through the joint research project with NNSA, IBM, Argonne and Lawrence Livermore National Laboratories—an IBM Blue Gene/Q—that is supported through the Research and Evaluations Prototypes activity.

The National Energy Research Scientific Computing (NERSC) facility at Lawrence Berkeley National Laboratory (LBNL) will operate at a capacity of over 356 teraflops in FY 2010 and will provide the production computing resources for the Office of Science programs. Focus will be on assisting applications to effectively utilize the potential of this facility and to move beyond NERSC to the larger LCF machines. Acquisition of NERSC 6 in FY 2010 will bring total NERSC capacity to approximately one petaflop to meet ever growing demand from Office of Science researchers.

The FY 2010 budget request supports ESnet to continue to advance the next generation network capability that is critical to Department applications and facilities. ESnet will deliver 100–400 gigabits per second (Gbs) connections to Office of Science laboratories in FY 2010, with a goal of achieving 1,000 Gbs connectivity in 2014. These increases in bandwidth are necessary to move massive amounts of data to and from the petascale computing facilities and from other research facilities such as the Large Hadron Collider and Spallation Neutron Source. The ESnet is also critical to effective utilization of the growing amounts of data in climate research, nuclear structure, genomics, and proteomics that advance the Department's energy and environment missions.

The FY 2010 budget continues the research efforts in Scientific Discovery through Advanced Computing (SciDAC) and the core research programs in Applied Mathematics and Computer Science that enable scientists to effectively utilize the capabilities of the LCFs while beginning to lay the basic research foundation necessary to realize the potential from the more complex systems on the horizon. Increases in core research in Applied Mathematics and Computer Science for FY 2010 will be targeted at long-term research needs. In networking, the growing amounts of scientific data and the need to remotely access large-scale scientific facilities will challenge the current network infrastructure. New technologies are emerging to enhance the capacity of the existing network but new techniques and tools will need to be developed to effectively utilize that capacity. The Next Generation Networking for Science research portfolio was re-competed in FY 2009 to address the most critical research needs for these next generation scientific networks.

**Significant Program Shifts**

A new allocation option for the ASCR scientific computing facilities was established in FY 2009 called the ASCR Leadership Computing Challenge program. This program is open year-round to scientists from the research community in academia and industry and allocates up to 30 percent of the computational resources at NERSC and the LCFs at Argonne and Oak Ridge for special situations of interest to the Department with an emphasis on high-risk, high-payoff simulations in areas directly related to the Department's energy mission, for national emergencies, or for broadening the community of researchers capable of using leadership computing resources. The majority of the LCF resources will continue to be allocated through INCITE. NERSC will be focused on the program priorities of the Office of Science.

## Mathematical, Computational, and Computer Sciences Research

### Funding Schedule by Activity

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Mathematical, Computational, and Computer Sciences Research | | | |
| Applied Mathematics | 32,146 | 40,164 | 44,850 |
| Computer Science | 24,121 | 33,618 | 46,800 |
| Computational Partnerships | 54,053 | 52,064 | 53,235 |
| Next Generation Networking for Science | 7,580 | 14,321 | 14,321 |
| SBIR/STTR | — | 4,038 | 4,586 |
| Total, Mathematical, Computational, and Computer Sciences Research | 117,900 | 144,205 | 163,792 |

## Description

The Mathematical, Computational, and Computer Sciences Research (Research) subprogram supports the research elements of the ASCR program to effectively utilize forefront computational and networking capabilities. Computational science is increasingly central to progress at the frontiers of science and to our most challenging feats of engineering. Accordingly, the Research subprogram must be positioned to address scientifically challenging questions, such as:

- What new mathematics are required to accurately model systems such as the earth's climate or the behavior of living cells that involve processes taking place on vastly different time and/or length scales?
- Which computational architectures and platforms will deliver the most benefit for the science of today and the science of the future?
- What advances in computer science and algorithms are needed to increase the efficiency with which supercomputers solve problems?
- What operating systems, data management, analysis, representation model development, user interface, and other tools are required to make effective use of future-generation supercomputers?
- What tools are needed to make all scientific resources readily available to scientists, regardless of whether they are at a university, national laboratory, or industrial setting?

## FY 2008 Accomplishments

- *SciDAC team wins 2008 Gordon Bell special prize for algorithms*. The SciDAC team won for developing the Linearly Scaling 3D Fragment (LS3DF) Method, which was used to predict the energy harnessing efficiency of nanostructures that can be used in solar cell design. The team computed the electronic structure of a 3,500-atom ZnTeO (zinc-telluride-oxygen) alloy to verify that the code could be used to predict properties of the alloy that had previously been experimentally observed. The simulation led to a prediction for the efficiency of this alloy as a new solar cell material. The prestigious Gordon Bell special prize was awarded for the clever way in which the code reduces the complexity of the problem to something within reach of today's computers without sacrificing scientific content.

- *First-Principles flame simulation provides crucial information to guide design of fuel-efficient cleaner engines.* Combustion models for designing tomorrow's vehicle engines and power generation devices challenge the capabilities of the most advanced computers but provide valuable insights toward improving efficiency and reducing emissions. These researchers managed to model flames with a wide-range of characteristics. They found that if low-temperature compression ignition concepts employing lean dilute fuel mixes are widely adopted in next generation engines, fuel efficiency could increase by as much as 25-50%. This approach would also help meet future low-emission vehicle standards with almost undetectable emissions of nitrogen oxide, a major contributor to smog.
- *First provably scalable solver for Maxwell's equations*. A team of applied mathematicians has developed the first provably scalable solver code for Maxwell's equations, a set of equations that are fundamental to physics and engineering of electric and magnetic fields. This novel software technology, known as an auxiliary-space Maxwell solver, outperforms earlier solution techniques by as much as 25 times. This enables researchers to solve large-scale computational electromagnetics problems with far greater accuracy. Electromagnetic simulations have a wide range of applications such as in the development of pulsed-power devices, semiconductor chips, stealth aircraft, and electrical generators.
- *Powerful mathematical tools resolve complex simulations.* PETSc (Portable, Extensible Toolkit for Scientific computation) was developed as a general purpose suite of tools for solving equations used in large-scale application projects. The PETSc solvers are used to model complex phenomena in virtually all areas of DOE-sponsored science and engineering research, including climate science, fission and fusion energy, nanoscience simulations, subsurface flows, oil-reservoir modeling, combustion, fracture mechanics, and micromagnetics. A 2009 example of an application using PETSc is PFLOTRAN, a next generation reactive flow and transport model that provided important information about reducing uranium concentrations at the Hanford 300 site.
- *Astrophysicists discover supernova shock-wave instability and a better way to spin up pulsars.* SciDAC researchers have provided two key pieces in the puzzle of the core-collapse supernova, demonstrating that the supernova shock wave is unstable and showing how the shock wave instability may be responsible for the spin of the leftover pulsar. Their efforts help us understand how some of the universe's most dramatic catastrophes are responsible for producing and spreading the Elements of life.
- *SciDAC accelerator project influences accelerator design and addresses construction challenges at DOE facilities.* The Community Petascale Project for Accelerator Science and Simulation (ComPASS) project, in collaboration with one of the math-focused Centers for Enabling Technologies, developed an uncertainty quantification tool to reconstruct the cavity shape of a particle accelerator using measured data as inputs. The tool successfully identified the cause of the beam breakup instability in a cryomodule of the 12 GeV CEBAF Upgrade Project at the Thomas Jefferson National Accelerator Facility and the findings helped the project move into construction.

## Detailed Justification

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| **Applied Mathematics** | **32,146** | **40,164** | **44,850** |

The Applied Mathematics activity supports the research, development, and application of applied mathematical models, methods and algorithms to understand complex physical, chemical, biological, and engineered systems related to the Department's mission. The research falls into eight general categories described below. The first five have been supported for a number of years and the last three began in FY 2009.

- Numerical methods research for equations related to problems such as wave propagation, electrodynamics, fluid flow, elasticity, and other natural or physical processes.
- Advanced linear algebra research for fast and efficient numerical solutions of linear algebraic equations that often arise when simulating physical processes. Because a large fraction of the time in many simulations is spent doing this type of computation, advances here have enormous leverage across science.
- Computational meshing research for developing ways in which space can be broken up into regions—often geometrically complex—for the purposes of simulation.
- Optimization research for mathematical methods for minimizing energy or cost, or finding the most efficient solutions to engineering problems, or discovering physical properties and biological configurations. This includes optimization, control, and risk assessment in complex systems with relevance for DOE missions in energy, national security, and environment.
- Multiscale mathematics and multiphysics computations for connecting the very large with the very small, the very long with the very short, and multiple physical models in a single simulation.
- Joint Applied Mathematics-Computer Science Institutes for the development of efficient new mathematical models, algorithms, libraries, and tools for next generation computers.
- Mathematics for the analysis of extremely large datasets for identifying key features, determining relationships between the key features, and extracting scientific insights.
- Mathematics of cyber security from a basic research perspective for addressing the understanding and discovery of anomalies in existing network data, modeling of large-scale networks, and understanding dynamics and emergent behavior on networks. This leverages on-going efforts in the mathematics of optimization and risk assessment in complex systems.

These mathematical models, methods and algorithms are the fundamental building blocks for describing physical systems computationally. Applied Mathematics research underpins all of the modeling and simulation efforts in the Department.

In FY 2010, the Applied Mathematics activity will support the long term cyber security challenges of open science that was transferred from Next Generation Networking for Science and initiated in FY 2009. Early career awards given to exceptionally talented university investigators in Applied Mathematics will also continue to be supported. The Computational Science Graduate Fellowship program, aimed at attracting the best graduate students in the scientific disciplines and educating them

| | (dollars in thousands) | |
|---|---|---|
| FY 2008 | FY 2009 | FY 2010 |

as the next generation of computational scientists, is continued at $6,000,000. In addition, in FY 2010 the Applied Mathematics activity will initiate a new fellowship program for graduate students and young investigators in applied mathematics and high performance computer science.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **Computer Science** | **24,121** | **33,618** | **46,800** |

The Computer Science activity supports research to utilize computing at extreme scales and to understand extreme scale data from both simulations and experiments. The research falls into five general categories described below. The first four have been supported for a number of years and the last was begun in FY 2009.

- Operating and file systems for extreme scale computers with many thousands of multi-core processors with complicated interconnection networks.
- Performance and productivity tools for extreme scale systems that enable users to diagnose and monitor the performance of software and scientific application codes to enable users to improve performance and get scientific results faster.
- Programming models that enable today's computations and discover new models that scale to hundreds of thousands of processors to simplify application code development for petascale computing.
- Data management and visualization: to transform extreme scale data into scientific insight through investments in visualization tools that scale to multi-petabyte datasets and innovative approaches to indexing and querying data.
- Joint Applied Mathematics-Computer Science Institutes for the development of efficient new mathematical models, algorithms, libraries, and tools for next generation computers. Leading edge developers to directly address the new challenges from the next generation of computers and transfer this insight to key DOE application developers.

The Computer Science activity addresses two fundamental challenges. The first challenge is enabling science applications to harness computer systems with increasing scale and increasing complexity due to technology advances such as multicore chips. This challenge will require more dynamic behavior of system software (operating systems, file systems, compilers, performance tools) than historically developed. Substantial innovation is needed to provide essential system software functionality in a timeframe consistent with the anticipated availability of hardware. The second challenge is enabling scientists to effectively manage, analyze and visualize the petabytes of data that result from extreme scale simulations and experimental facilities. Substantial innovation in computer science and applied mathematics is needed to provide essential system and application functionality in a timeframe consistent with the anticipated availability of hardware.

In FY 2010, the Computer Science activity will initiate a new effort in advanced computer architecture design for science to ensure that ASCR will be actively engaged in the early stages of continued advancement in high performance computing systems suitable for DOE's scientific applications. This new effort will focus on pre-competitive research that falls short of the fabrication and testing of prototypes, and will involve close coordination with other agencies and high performance computing vendors. In addition, the Computer Science activity will expand support for the most promising long-term research to address the challenges of next generation computing systems and extreme scale data.

This research will bridge efforts in advanced computer architecture design with ongoing efforts in computer science and applied mathematics to address the specific needs of DOE science applications. Early career to exceptionally talented university investigators in Computer Science will also continue.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **Computational Partnerships** | **54,053** | **52,064** | **53,235** |

The Computational Partnership activity supports the Scientific Discovery through Advanced Computing (SciDAC) program to use results from applied mathematics and computer science research on scientific applications sponsored by other Office of Science programs. These partnerships enable improved performance on high-end computing systems for scientists to conduct complex scientific and engineering computations at a level of detail that begin to resemble real-world conditions. The activities fall into four general categories described below.

- The nine multi-institutional *Centers for Enabling Technologies* represent almost half of the ASCR SciDAC activity. They are a focal point for bringing together a critical mass of leading experts from multiple disciplines to focus on key problems in a particular area such as performance, data management, optimization, or visualization. These SciDAC Centers address needs for new methods, algorithms and libraries; new methodologies for achieving portability and interoperability of complex scientific software packages; software tools and support for application performance; and more effective tools for feature identification, data management, and visualization.
- The four multi-institutional *SciDAC Institutes* are university-led centers of excellence which complement the efforts of the SciDAC Centers for Enabling Technologies but with a role in the education and training of the next generation of computational scientists. These institutes reach out to a broader community of scientists to advance scientific discovery through advanced computation, collaboration, and training of graduate students and postdoctoral fellows.
- The 35 multi-institutional *Science Applications Partnerships* are partnerships with other Office of Science programs to dramatically improve the ability of their researchers to effectively utilize petascale computing to advance science. These partnerships support collaborative research between applied mathematicians and computer scientists (supported by ASCR) with domain scientists (supported by the other programs) to refine and apply computational techniques and tools that address the specific problems of a particular research effort, such as modeling the reactive transport of contaminants through groundwater or developing an Earth System model that fully simulates the coupling between the physical, chemical, and biogeochemical processes in the global climate.
- With more than 80 participating institutions and hundreds of researchers developing tools, techniques, and software that push the state-of-the-art in high performance computing, ASCR needed to ensure that SciDAC teams shared information across projects and, to leverage taxpayer investment, with other researchers. The *SciDAC Outreach Center*, a small virtual organization linked to user support at the ASCR facilities and organized by LBNL, provides a single resource to facilitate and accelerate the transfer of tools, techniques, and methods to the broader research community. The SciDAC Outreach Center is also a resource for INCITE applicants who need assistance in readying their application for leadership facilities.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |

In FY 2010, the Computational Partnerships activity will support a small number of new interdisciplinary teams focused on transforming critical DOE applications for extreme scale computing. These competitively selected teams will evaluate the impact of directions in computer hardware on application capability, form a critical interface to existing SciDAC Centers and Institutes on the tool and library implications of these developments and develop the understanding needed to enable these applications to execute effectively on future computer architectures.

| | | | |
|---|---|---|---|
| **Next Generation Networking Research for Science** | **7,580** | **14,321** | **14,321** |

The Next Generation Networking for Science activity builds on results from Computer Science and Applied Mathematics to develop integrated software tools and advanced network services to enable large-scale scientific collaboration and to utilize the new capabilities of ESnet to advance DOE missions. The research falls into two general categories described below.

- Distributed systems software including scalable and secure tools and services to facilitate large-scale national and international scientific collaboration and high-performance software stacks to enable the discovery, management, and distribution of extremely large data sets generated by simulations or by science experiments such the Large Hadron Collider, the Intergovernmental Panel on Climate Change, and ITER.
- Advanced network technologies including dynamic optical network services, scalable cyber security technologies, and multi-domain, multi-architecture performance protocols to seamlessly interconnect and provide access to distributed computing resources and science facilities.

In FY 2010, Next Generation Networking for Science activity transfers long term cyber security research to the Applied Mathematics activity and will initiate new research efforts to focus on developing technologies to support research and education networks such as ESnet. Early career awards given to exceptionally talented university investigators in Networking will also continue to be supported.

| | | | |
|---|---|---|---|
| **Small Business Innovative Research (SBIR)/ Small Business Technology Transfer (STTR)** | **—** | **4,038** | **4,586** |

In FY 2008, $3,354,000 and $403,000 were transferred to the SBIR and STTR programs respectively. The FY 2009 and FY 2010 amounts shown are the estimated requirements for continuation of the congressionally mandated SBIR and STTR programs.

| | | | |
|---|---|---|---|
| **Total, Mathematical, Computational, and Computer Sciences Research** | **117,900** | **144,205** | **163,792** |

## Explanation of Funding Changes

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| **Applied Mathematics** | |
| This increase reflects the shift of cyber security research from Next Generation Networking for Science to Applied Mathematics and supports a new fellowship program for graduate students and young investigators in applied mathematics and high performance computer science. | +4,686 |
| **Computer Science** | |
| This increase will support a new effort in advanced computer architecture design for science and will expand support for the most promising long-term research to address the challenges of next generation computing systems and extreme scale data. This research will bridge efforts in advanced computer architecture design with ongoing efforts in computer science and applied mathematics to address the specific needs of DOE science applications. | +13,182 |
| **Computational Partnerships** | |
| The increase will support a small number of interdisciplinary teams focused on transforming critical DOE applications for extreme scale computing. | +1,171 |
| **SBIR/STTR** | |
| Increase in SBIR/STTR due to increase in operating expenses. | +548 |
| **Total Funding Change, Mathematical, Computational, and Computer Sciences Research** | **+19,587** |

## High Performance Computing and Network Facilities

### Funding Schedule by Activity

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| High Performance Computing and Network Facilities | | | |
| High Performance Production Computing | 56,700 | 54,790 | 55,000 |
| Leadership Computing Facilities | 114,065 | 115,000 | 130,000 |
| Research and Evaluation Prototypes | 25,347 | 23,900 | 23,900 |
| High Performance Network Facilities and Testbeds | 27,762 | 25,000 | 29,862 |
| SBIR/STTR | — | 5,925 | 6,446 |
| Total, High Performance Computing and Network Facilities | 223,874 | 224,615 | 245,208 |

## Description

The High Performance Computing and Network Facilities (Facilities) subprogram delivers forefront computational and networking capabilities to scientists nationwide.

To maintain leadership in areas of scientific modeling and simulation important to DOE missions, the Facilities subprogram plans, develops, and operates high performance computing facilities and advanced networks that are available 24 hours a day, 365 days a year. This includes the High Performance Production Computing at the National Energy Research Scientific Computing (NERSC) facility at LBNL, Leadership Computing Facilities (LCFs) at Oak Ridge and Argonne National Laboratories, and High Performance Network Facilities and Testbeds through the Energy Sciences Network (ESnet) managed by LBNL. The Facilities subprogram also invests in long-term needs through the Research and Evaluation Prototypes activity.

The Facilities subprogram contributes to DOE missions by providing the leadership and high performance computing facilities and scientific networks that support mission driven and open science research. These computers, and the other SC research facilities, turn out many petabytes of data each year. Moving these data to the researchers who need them requires advanced scientific networks and related technologies also provided through the Facilities subprogram.

The Facilities subprogram computing resources are allocated through competitive processes. The LCFs are predominately allocated through the Innovative and Novel Computational Impact on Theory and Experiment (INCITE) program to researchers at universities, national laboratories, and foreign institutions. Up to eighty percent of the processor time on LCFs is allocated through INCITE to a small number of projects, each requiring a substantial amount of the available resources. LCFs provided over 889 million hours of computing time in calendar year 2009. The high performance production computing facilities at NERSC are focused on the computing needs of the SC and allocated through a competitive process reserved for researchers supported by the SC programs. In FY 2010, all of the ASCR scientific computing facilities will allocate up to thirty percent of computing resources through the ASCR Leadership Computing Challenge program as described under Significant Program Shifts.

## FY 2008 Accomplishments

- *World's first petascale application provides new insights into superconductivity.* Researchers simulated chemical disorder in high-temperature superconductors known as cuprates—layers of copper oxide separated by layers of an insulating material. These simulations were the first where there was enough computing power to move beyond ideal, perfectly ordered materials. By advancing understanding of the interplay between these imperfections and superconductivity, the work promises to help researchers push transition temperatures ever higher, possibly approaching the goal of room-temperature superconductivity, or materials that exhibit this behavior without artificial cooling. This work received the prestigious 2008 Association for Computing Machinery Gordon Bell Prize for attaining the fastest performance ever in a scientific supercomputing application—1.352 quadrillion calculations a second, or 1.352 petaflops—on the Oak Ridge LCF.
- *Oak Ridge leadership computing facility world's first petaflop computer dedicated to open science.* The latest upgrade to the LCF increases the system's computing power to a peak 1.64 petaflops, or quadrillion mathematical calculations per second. The project to build a petaflops machine—completed on time, on budget and exceeding the original scope—included partnerships with industry to develop new hardware and computer architectures. The LCF is made available to the scientific community through SC's peer-reviewed INCITE program. In 2008, INCITE research included accelerator physics, astrophysics, chemical sciences, climate research, computer science, engineering physics, environmental science, fusion energy, life sciences, materials science, nuclear physics, and nuclear engineering. Practical applications of the research include improving commercial aircraft design, advancing fusion energy, studying supernova, understanding nanomaterials, and studying global climate change and the causes of Parkinson's disease.
- *National Energy Research Scientific Computing (NERSC) facility research advances goals for a green economy.* Researchers investigating the renewable production and storage of hydrogen at NERSC have uncovered ways of reducing carbon dioxide using methods that mimic photosynthesis. These results open new opportunities for photochemical reactions by visible-light irradiation and was the cover article for the May 2008 issue of Inorganic Chemistry.
- *Argonne Leadership Computing Facility (ALCF) uses an innovative cooling system to reduce power consumption.* Among the top 20 supercomputers in the world in November, 2008, the ALCF is the second-most energy-efficient and needs only a little more than one megawatt of power. Much of the electricity that the ALCF requires is not actually used to process computations but rather to cool machinery. Without any cooling at all, the room that houses the computer and peripherals would reach 100 degrees Fahrenheit in ten minutes after the equipment is powered on. To reduce the amount of electricity used, the ALCF was able to take advantage of Chicago's cold winters and replaced air conditioners with fans to move 300,000 cubic feet of water-chilled air per minute to maintain a room temperature of 64 degrees Fahrenheit. The technique uses only 60 percent more energy for cooling than the supercomputer itself draws, compared to over twice the power for typical supercomputers. In addition, the ALCF's chilled water plant uses cooling towers to chill the water when the weather is cold. Once the temperature falls to 35 degrees Fahrenheit or below outside, the temperature in the chilled water system is maintained solely by Argonne's cooling towers saving about $20,000 to $25,000 a month in electrical costs.
- *Energy Sciences Network (ESnet) launches first segment of the next-generation nationwide scientific research network.* The Department of Energy completed upgrades to ESnet4 in December 2008. ESnet4 is one of the most advanced and reliable, high capacity nationwide networks supporting

scientific research. By providing reliable high bandwidth access to DOE laboratories and other major research facilities, ESnet4 will enhance the capabilities of researchers and scientists across the country to advance the scientific mission of the Department. Furthermore, because of the infrastructure and design of ESnet4, it will be upgraded seamlessly to meet the growing, complex needs of the Department.

## Detailed Justification

(dollars in thousands)

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **High Performance Production Computing** | **56,700** | **54,790** | **55,000** |

This activity supports the NERSC facility located at LBNL. NERSC delivers high-end capacity computing services and supports the SC research community. Nearly 3,100 computational scientists in about 400 projects use NERSC to perform basic scientific research across a wide range of disciplines including astrophysics, chemistry, climate modeling, materials, analysis of data from high energy and nuclear physics experiments, investigations of protein structure, and a host of other scientific endeavors. NERSC enables teams to prepare to use the LCFs as well as to perform the calculations that are required by the missions of the SC programs. NERSC users are supported by Office of Science programs with 60% based in universities, 29% in national laboratories, 6% in other government laboratories, and 3% in industry.

The costs for NERSC fall into three general areas: lease payments for high performance computing hardware, operations (space, power, cooling, maintenance, tapes, etc.), and operating and support staff. NERSCs large user base requires an extremely agile support staff. Careful planning of upgrades is critical to meeting increasing demand within a stable funding profile.

FY 2010 funding will support operation of the NERSC high-end capability systems (NERSC-5 and NERSC-6), lease payments and user support. In FY 2010, the total capacity of NERSC will be approximately one petaflop with the acquisition and operation of NERSC-6. Two systems were decommissioned in FY 2009, Jaquard and Bassi. The Bassi system was replaced with the competitively selected NERSC-6. These computational resources are integrated by a common high performance file storage system that enables users to easily migrate to any of the NERSC resources. With many petabytes of storage and an average transfer rate in the hundreds of megabytes per second this system also allows users to easily move data into and out of the NERSC facility.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| Achieved Operating Hours | 8,585 | N/A | N/A |
| Planned Operating Hours | 8,585 | 8,585 | 8,585 |
| Optimal Hours | 8,760 | 8,760 | 8,760 |
| Percent of Optimal Hours | 100% | 100% | 100% |
| Unscheduled Downtime | 1% | 1% | 1% |
| Number of Users | 2,500 | 3,100 | 3,100 |

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| **Leadership Computing Facilities (LCF)** | **114,065** | **115,000** | **130,000** |

The LCF activity was initiated in FY 2004 to enable open scientific applications to harness the potential of leadership computing to advance science. FY 2009 saw the realization of that vision, with four ASCR systems in the top ten of the independent international "Top 500" ranking of supercomputers—including the top system available for open science in two consecutive lists—and the world's first petascale science application which provided new insights into superconductivity. FY 2010 will be the first full year of operation of the petaflop leadership system at Oak Ridge and the 500 teraflop leadership system at Argonne. This new era of petaflop science opens significant opportunities to dramatically advance research as simulations more realistically capture the behavior of materials and ITER scale fusion devices. The success of this effort is built on the gains made in research and evaluation prototypes and the SciDAC program and on years of research in applied mathematics and computer science.

The costs for the LCFs fall into three general areas: lease payments, operations (space, power, cooling, maintenance, tapes, etc), and operating and support staff. In FY 2010, costs are driven by increases in lease payments at both facilities in accordance with the approved baselines.

| | | | |
|---|---|---|---|
| ▪ **Leadership Computing Facility at ORNL (OLCF)** | **84,716** | **85,000** | **88,000** |

The first LCF capability for science was established in late FY 2005 at ORNL. In FY 2009, the facility accepted a 1.382 petaflop (1,382 teraflops) Cray Baker system which, when combined with the 263 teraflop machine can achieve a theoretical peak of 1.645 petaflops. The Baker system was accepted in FY 2009 and is expected to complete transition to operations by the end of FY 2009. Some applications, particularly in superconductivity and fusion research, are already achieving sustained performance in excess of 1.3 petaflops or over 80% of the peak capability.

In FY 2010, increases in the lease payments are partially offset by reductions in activities such as enhancing data storage and other site preparation for the petaflop system that were completed in FY 2009. The OLCF activity will support operation and INCITE allocation of the 1.645 petaflop combined system in FY 2010 and will continue to support INCITE projects, ASCR Leadership Computing Challenge projects, scaling tests, and tool and library developers.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| Achieved Operating Hours | 7,008 | N/A | N/A |
| Planned Operating Hours | 7,008 | 7,008 | 7,008 |
| Optimal Hours | 7,008 | 7,008 | 7,008 |
| Percent of Optimal Hours | 100% | 100% | 100% |
| Unscheduled Downtime | 1% | 1% | 1% |
| Number of Users | 400 | 400 | 400 |

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| ▪ **Leadership Computing Facility at ANL (ALCF)** | **29,349** | **30,000** | **42,000** |

Diversity in the LCF resources is achieved by operation of the ALCF high performance IBM Blue Gene/P with low-electrical power requirements and a peak capability of 556 teraflops. This facility provides many applications, including molecular dynamics and materials, with access to a system that is better suited to their computing needs than the OLCF and NERSC. In FY 2009, the ALCF completed transition to operation of the IBM Blue Gene/P and provided nine months of operations for INCITE users.

In FY 2010, funding increases support strengthening the Argonne infrastructure and increases in the lease payments on the Blue Gene/P in accordance with the approved schedule. Strengthening the infrastructure in FY 2010, including the start of site preparations, will be essential to prepare the facility for a next generation machine such as the one being developed through the joint research project with NNSA and IBM on the Blue Gene/Q. The ALCF activity will also support operation and INCITE allocation of the Blue Gene/P in FY 2010 and will continue to provide support to INCITE projects, pioneer applications, and tool and library developers.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| Achieved Operating Hours | 6,000 | N/A | N/A |
| Planned Operating Hours | 6,000 | 7,008 | 7,008 |
| Optimal Hours | 6,000 | 7,008 | 7,008 |
| Percent of Optimal Hours | 100% | 100% | 100% |
| Unscheduled Downtime | 1% | 1% | 1% |
| Number of Users | 50 | 100 | 200 |

| | | | |
|---|---|---|---|
| **Research and Evaluation Prototypes** | **25,347** | **23,900** | **23,900** |

The Research and Evaluation Prototype activity addresses the challenges of the systems that will be available by the end of the decade. We anticipate that these systems will be significantly more complex than current computing systems. As a result, many of the tools and techniques developed over the past decade will no longer be effective. By actively participating in the development of these next-generation machines, researchers will better understand their inherent challenges and can begin to work on overcoming those challenges. This activity will prepare researchers to effectively utilize the next generation of scientific computers and will also reduce the risk of future major procurements.

In FY 2010, the Research and Evaluation Prototypes activity will be carried out in close partnership with the NNSA and the Defense Advanced Research Projects Agency (DARPA) program for High Productivity Computing Systems (HPCS). This activity supports completion of both the DOE partnership in the DARPA HPCS Phase III program ($19,500,000) and SC’s participation in the joint SC-NNSA partnership with IBM to explore and advance low power density approaches to petascale computing ($4,400,000).

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| (dollars in thousands) | | | |
| **High Performance Network Facilities and Testbeds** | **27,762** | **25,000** | **29,862** |

This activity supports operation and upgrades for the Energy Science network (ESnet) including a related research partnership with Internet2. The ESnet provides a high bandwidth network connecting DOE researchers with large-scale scientific user facilities and other scientific instruments. Each year the amount of data generated by these facilities roughly doubles. To meet demand, ESnet has partnered with Internet2—the leading provider of university networks—to push the state-of-the-art and deliver next generation optical network technologies that greatly expand capacity in the core science networks. Continued progress in high performance networks builds on the tools and knowledge developed by the Next Generation Networks for Science research activity and by innovations developed in partnership with Internet2.

The costs for ESnet are dominated by operations which includes refreshing hardware, such as switches and routers, on an accelerated schedule to ensure the 99.99% reliability that is required for large scale scientific data transmission.

In FY 2009, a Recovery Act supported research effort will begin to implement a National testbed of next generation optical technologies that would allow networks, such as ESnet, to use the existing fiber plant but gain a ten fold increase in bandwidth. The testbed will allow ASCR to develop and harden the tools necessary to ensure data integrity and network reliability with this new technology. If successful, the Recovery Act project will allow ASCR to deploy this next generation technology (100 Gbps per wavelength) beginning in FY 2011. This would allow up to 400 Gbps total capacity to many SC laboratories in FY 2011 on a path to achieving 1,000 Gbps connectivity in FY 2014.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| Achieved Operating Hours | 8,760 | N/A | N/A |
| Planned Operating Hours | 8,760 | 8,760 | 8,760 |
| Optimal Hours | 8,760 | 8,760 | 8,760 |
| Percent of Optimal Hours | 100% | 100% | 100% |
| Unscheduled Downtime | 0.01% | 0.01% | 0.01% |
| Number of Users | N/A | N/A | N/A |

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **Small Business Innovative Research (SBIR)/ Small Business Technology Transfer (STTR)** | **—** | **5,925** | **6,446** |

In FY 2008, $5,038,000 and $604,000 were transferred to the SBIR and STTR programs respectively. The FY 2009 and FY 2010 amounts shown are the estimated requirements for continuation of the congressionally mandated SBIR and STTR programs.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **Total, High Performance Computing and Network Facilities** | **223,874** | **224,615** | **245,208** |

## Explanation of Funding Changes

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| **High Performance Production Computing** | |
| The increase will support operation of the NERSC high-end capability systems (NERSC-5 and NERSC-6), lease payments, and user support. | +210 |
| **Leadership Computing Facilities (LCFs)** | |
| The increase covers increases in lease payments at both facilities in accordance with approved schedule. The increase also supports the start of site preparation at Argonne National Laboratory for acquisition of a next generation machine. | +15,000 |
| **High Performance Network Facilities and Testbeds** | |
| The increase will enable ESnet to begin to deliver 100–400 Gbps connections to SC laboratories in FY 2010. The increase in bandwidth is critical to meeting the growing requirements for Department applications and facilities. | +4,862 |
| **SBIR/STTR** | |
| Increase in SBIR/STTR due to increase in operating expenses. | +521 |
| **Total Funding Change, High Performance Computing and Network Facilities** | **+20,593** |

## Supporting Information

### Operating Expenses, Capital Equipment and Construction Summary

(dollars in thousands)

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| Operating Expenses | 318,274 | 355,820 | 394,000 |
| Capital Equipment | 23,500 | 13,000 | 15,000 |
| Total, Advanced Scientific Computing Research | 341,774 | 368,820 | 409,000 |

### Funding Summary

(dollars in thousands)

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| Research | | | |
| National Laboratories | 84,537 | 102,410 | 107,894 |
| Universities | 28,867 | 32,627 | 47,119 |
| Other[a] | 29,843 | 38,993 | 39,125 |
| Total, Research | 143,247 | 174,030 | 194,138 |
| Scientific User Facility Operations | 198,527 | 194,790 | 214,862 |
| Total, Advanced Scientific Computing Research | 341,774 | 368,820 | 409,000 |

### Scientific User Facility Operations

(dollars in thousands)

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| NERSC | 56,700 | 54,790 | 55,000 |
| ESnet | 27,762 | 25,000 | 29,862 |
| OLCF | 84,716 | 85,000 | 88,000 |
| ALCF | 29,349 | 30,000 | 42,000 |
| Total, Scientific User Facility Operations | 198,527 | 194,790 | 214,862 |

### Facilities Users and Hours

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| NERSC | | | |
| Achieved Operating Hours | 8,585 | N/A | N/A |
| Planned Operating Hours | 8,585 | 8,585 | 8,585 |
| Optimal Hours | 8,585 | 8,585 | 8,585 |
| Percent of Optimal Hours | 100% | 100% | 100% |
| Unscheduled Downtime | 1% | 1% | 1% |
| Number of Users | 2,500 | 3,100 | 3,100 |

[a] Includes $19,500,000 for DOE's partnership in the DARPA HPCS program.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ESnet | | | |
| Achieved Operating Hours | 8,760 | N/A | N/A |
| Planned Operating Hours | 8,760 | 8,760 | 8,760 |
| Optimal Hours | 8,760 | 8,760 | 8,760 |
| Percent of Optimal Hours | 100% | 100% | 100% |
| Unscheduled Downtime | 0.01% | 0.01% | 0.01% |
| Number of Users | N/A | N/A | N/A |
| OLCF | | | |
| Achieved Operating Hours | 7,008 | N/A | N/A |
| Planned Operating Hours | 7,008 | 7,008 | 7,008 |
| Optimal Hours | 7,008 | 7,008 | 7,008 |
| Percent of Optimal Hours | 100% | 100% | 100% |
| Unscheduled Downtime | 1% | 1% | 1% |
| Number of Users | 400 | 400 | 400 |
| ALCF | | | |
| Achieved Operating Hours | 6,000 | N/A | N/A |
| Planned Operating Hours | 6,000 | 7,008 | 7,008 |
| Optimal Hours | 6,000 | 7,008 | 7,008 |
| Percent of Optimal Hours | 100% | 100% | 100% |
| Unscheduled Downtime | 1% | 1% | 1% |
| Number of Users | 50 | 100 | 200 |
| Total | | | |
| Achieved Operating Hours | 30,353 | N/A | N/A |
| Planned Operating Hours | 30,353 | 31,361 | 31,361 |
| Optimal Hours | 30,353 | 31,536 | 31,536 |
| Percent of Optimal Hours | | | |
| Unscheduled Downtime | 1% | 1% | 1% |
| Number of Users | 2,900 | 3,600 | 3,700 |

## Scientific Employment

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| # University Grants | 211 | 224 | 260 |
| Average Size | $270,000 | $281,000 | $296,000 |
| # Laboratory Projects | 165 | 175 | 180 |
| # Graduate Students (FTEs) | 495 | 533 | 563 |
| # Permanent Ph.D.s (FTEs) | 698 | 735 | 766 |
| # Other (FTEs) | 239 | 248 | 246 |

## Biological and Environmental Research

## Funding Profile by Subprogram (Non-Comparable, or as Appropriated, Structure)

(dollars in thousands)

| | FY 2008 Current Appropriation | FY 2009 Current Appropriation | FY 2009 Additional Appropriation[a] | FY 2010 Request to Congress |
|---|---|---|---|---|
| Biological and Environmental Research | | | | |
| Biological Research | 397,976 | 423,613 | 100,793 | — |
| Climate Change Research | 133,087 | 177,927 | 64,860 | — |
| Biological Systems Science | — | — | — | 318,476 |
| Climate and Environmental Sciences | — | — | — | 285,706 |
| Total, Biological and Environmental Research | 531,063[bc] | 601,540 | 165,653 | 604,182 |

## Funding Profile by Subprogram (Comparable Structure to the FY 2010 Request)

(dollars in thousands)

| | FY 2008 Comparable Appropriation | FY 2009 Comparable Appropriation | FY 2009 Additional Appropriation[a] | FY 2010 Request to Congress |
|---|---|---|---|---|
| Biological and Environmental Research | | | | |
| Biological Systems Science | 303,961 | 322,815 | 40,793 | 318,476 |
| Climate and Environmental Sciences | 227,102 | 278,725 | 124,860 | 285,706 |
| Total, Biological and Environmental Research | 531,063[bc] | 601,540 | 165,653 | 604,182 |

**Public Law Authorizations:**
Public Law 95–91, "Department of Energy Organization Act", 1977
Public Law 109–58, "Energy Policy Act of 2005"
Public Law 110–69, "America COMPETES Act of 2007"

Modifications were made to the budget structure to better reflect the subprogram's activities in FY 2010. The two tables above show a non-comparable and comparable funding profile for the subprogram. The non-comparable table presents the FY 2010 funding in the new budget structure only and FY 2008 and FY 2009 funding is shown as appropriated. The comparable table shows the FY 2008 and FY 2009 funding in the new budget structure to assist in comparing year-to-year funding trends. A crosswalk of the new and old structure is provided at the end of this chapter, describing in detail the modification to the budget structure.

[a] The Additional Appropriation column reflects the planned allocation of funding from the American Recovery and Reinvestment Act of 2009, P.L. 111–5. See the Department of Energy Recovery website at http://www.energy.gov/recovery for up -to-date information regarding Recovery Act funding.
[b] Total is reduced by $13,334,000: $12,065,000 of which was transferred to the Small Business Innovative Research (SBIR) program and $1,269,000, of which was transferred to the Small Business Technology Transfer (STTR) program.
[c] The Congressional control level in FY 2008 and FY 2009 is at the Biological Research and Climate Change Research levels.

## Program Overview

### Mission

The mission of the Biological and Environmental Research program is to understand complex biological, climatic, and environmental systems across spatial and temporal scales ranging from sub-micron to the global, from individual molecules to ecosystems, and from nanoseconds to millennia. This will be accomplished by exploring the frontiers of genome-enabled biology; discovering the physical, chemical and biological drivers of climate change; and seeking the molecular determinants of environmental sustainability and stewardship.

### Background

The wonders of planet Earth, how it works, and how we can sustain it for future generations are the subject of discussion and debate from the classroom to the editorial page to the pages of scientific journals. We hear arguments about the threat and controversy of global warming, rising greenhouse gases, and increasing temperatures; about the promise of biofuels and concerns that we will be able to produce sufficient, affordable quantities in a manner that protects the environment; and about the challenge of protecting our rivers and aquifers from environmental contaminants left as a legacy of nuclear weapons development. Each of these practical challenges, questions, and arguments is driven by a base of scientific knowledge and inquiry in atmospheric chemistry and physics, ecology, genetics, and subsurface science. What determines Earth's climate? How does a genome give life to microbes, plants, and ecosystems? What are the biological and physical forces that govern the behavior of Earth's subsurface environment? The Office of Biological and Environmental Research (BER) program supports research addressing these questions, providing understanding of nature that enables DOE to find solutions to our energy and environmental challenges.

BER's origins date to 1946, the atomic bomb, concerns for health effects from exposure to radiation, and the promise of benefits from peaceful uses of nuclear energy. Health effects research gave us breakthroughs in genetics and developments in nuclear medicine, such as radioisotopes for common medical tests and computed tomography (CT) and positron emission tomography (PET) scanners that still benefit millions of patients each year. Interest in the effects of radiation exposure led to understanding the most fundamental level of biology, DNA, and in turn led DOE to initiate the Human Genome Project, spearheading today's biotechnology revolution. The need to understand the global distribution of fallout from weapons tests in the 1950s and 1960s led DOE to develop the first ecological research programs, research to understand clouds, models to predict the behavior of particles in the atmosphere, and today, models to understand and predict future climate.

Today, the BER science portfolio includes research programs and user facilities that address some of the most exciting problems in biological, climatic, and environmental research. BER research uncovers Nature's secrets from the diversity of microbes and plants to understand how biological systems work, how they interact with each other, and how they can be manipulated to harness their processes and products. By starting with an organism's DNA, BER-funded scientists seek to understand whole biological systems as they respond to and modify their environments. The biological systems that BER scientists investigate range from individual proteins and other molecules, to groups of molecules that comprise molecular machines, to interconnected biological networks within whole cells, communities, and ecosystems.

BER plays a vital role in supporting research on atmospheric processes, climate change modeling, interactions between ecosystems and greenhouse gases (especially carbon dioxide, $CO_2$), and analysis of impacts of climatic change on energy production and use. Understanding the Earth's radiant energy balance is the largest uncertainty in determining the rate of global change. BER supports research on the factors determining that balance—the role of different types of clouds, atmospheric particles, and greenhouse gases. BER also supports research to understand the impacts of climatic change—warmer temperatures, changes in precipitation, increased levels of greenhouse gases—on different ecosystems such as forests, grasslands, and farmland. The Earth's subsurface is a new frontier for discovering novel microorganisms and understanding important geochemical and hydrological processes, including the fate of environmental contaminants.

A common theme across BER's research portfolio, indeed across the Office of Science, is the challenge and excitement of studying complex systems. BER's systems have their own unique complexity covering remarkable spatial and temporal scales. In living systems, whether a microbe, a microbial community, a plant, an entire ecosystem, or a person exposed to low doses of radiation, the scales of interest can be as small as the interactions of individual proteins or fragments of DNA within a single cell or as large as an entire organism—a microbe or a person—or even an entire forest of trees used as the starting material for producing biofuels or responding to climate change. The range of critical time scales in living systems is equally vast ranging from fractions of a second required for the interaction of biological molecules to the decades or even centuries to understand the long-term ecological impacts of a changing climate or the sustained production of specific crops for production of biofuels. A unique complexity to the study of spatial or temporal scales in living systems is the genetic capacity of those systems to directly regulate their interactions with other systems and to replicate themselves, features not found in other systems studied by the Office of Science. The ranges of scales of interest are equally complex for studies of Earth's climate and subsurface. Spatially these range from particles in a cloud or the subsurface environment to the Earth's entire atmosphere or a regional aquifer. At the temporal scale they also range from fractions of a second for interactions at the molecular level to decades or centuries to understand the long term effects of climate change or the behaviors of contaminants in the subsurface. BER science also exploits DOE's computational resources, developing computational models that can be used to make experimentally testable predictions about climate, complex subsurface environments, or biological systems. Today, computational models are an essential tool for all BER science.

Major scientific goals for BER are outlined below:

- **Genomic Science** conducts explorations of microbes and plants at the molecular, cellular, and community levels. The goal is to gain insights about fundamental biological processes and, ultimately, a predictive understanding of how living systems operate. A 2006 National Research Council review of the Genomic Science activity[a] supports and encourages the focus on microbes and plants and states that "systems biology research is needed to develop models for predicting the behavior of complex biological system."
- **Radiological Sciences** support research in radiochemistry and radiotracer development with the goal of developing new methodologies for real-time, high-resolution imaging of dynamic biological systems. This goal is supported by a 2009 community-based workshop, "New Frontiers of Science in Radiochemistry and Instrumentation for Radionuclide Imaging."[b] Radiobiology provides systems level research to understand radiation-induced perturbations of physiological processes.
- **Climate Research** supports research in atmospheric and environmental systems, and predictive climate and Earth system models. This research is guided by a seminal 2008 report by the BER Advisory Committee entitled, "Identifying Outstanding Grand Challenges in Climate Change Research: Guiding DOE's Strategic Planning."[c] The report recommended that BER research should

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[a] http://www.nap.edu/catalog/11581.html
[b] http://www.sc.doe.gov/ober/radiochem_2008workshop_report.pdf
[c] http://www.sc.doe.gov/ober/berac/Grand_Challenges_Report.pdf

"seek to understand Earth's climate system by characterizing current climate and its evolution over the last century to its present state, predicting regional climate change for the next several decades, and simulating Earth System changes and their consequences over centuries."

- **Subsurface Biogeochemistry** seeks to understand the role that subsurface biogeochemical processes play in determining the fate and transport of contaminants including heavy metals and radionuclides. Computational models of coupled biological, geochemical, and hydrological processes are needed to predict the rates and kinetics of transformation and sequestration of these critical DOE contaminants.

**Subprograms**

To accomplish its mission and address the scientific challenges described above, the BER program is organized into two subprograms, Biological Systems Science (BSS) and Climate and Environmental Sciences (CES).

- The *Biological Systems Science* subprogram explores the fundamental principles that drive the function and structure of living systems. The target systems range from microbes and microbial communities to plants and other whole organisms. Using the genome as a blueprint, Genomic Sciences provides the foundational biological understanding of microbial and plant systems in a range of natural and managed ecosystems. Three DOE Bioenergy Research Centers (BRCs)—led by Lawrence Berkeley National Laboratory, Oak Ridge National Laboratory, and the University of Wisconsin at Madison in partnership with Michigan State University—support multidisciplinary teams of leading scientists whose goal is to accelerate transformational breakthroughs needed to understand the conversion of cellulose (plant fibers) to biofuels. The Joint Genome Institute (JGI), a high-throughput DNA sequencing user facility, provides the basis for systems biology and unmatched capabilities to understand and predict the function of environmental and energy-related microbes and plants. Current sequencing capacity at the JGI is over124 billion base pairs per year (compared to about 3 billion base pairs for the entire human genome) and growing rapidly. To understand the proteins encoded by DNA, the Structural Biology activity supports access to DOE's world-class synchrotron and neutron sources. The interface between biology and the physical sciences is explored in the Radiological Sciences with new methods for real-time high resolution imaging of dynamic biological processes and with molecular and genomic biology to underpin radiation risk policy, as well as in Medical Applications where an artificial retina is being developed.
- The *Climate and Environmental Sciences* subprogram advances science to understand, predict, and mitigate the impacts of energy production and use on climate change. Atmospheric System Research supports data collection and experimentation, through its Atmospheric Radiation Measurement (ARM) activity, to help resolve the greatest uncertainties in climate change-the role of clouds and aerosols in Earth's radiation balance. The ARM Climate Research Facility (ACRF) provides key observational data to the climate research community on the radiative properties of the atmosphere, especially clouds. The facility includes highly instrumented ground stations, a mobile facility, and an aerial vehicles program; it served over 1000 users from around the world in FY 2008. Climate and Earth System Modeling supports some of the worlds most powerful and sophisticated climate models that contribute to reports by the Intergovernmental Panel on Climate Change. Integrated Assessment research develops models to identify options for and costs of climate change mitigation. Environmental Systems Science supports research to understand the impact on and role of diverse ecosystems on climate change, as well as subsurface biogeochemical research to understand and predict subsurface contaminant fate and transport. The Environmental Molecular Sciences Laboratory (EMSL) serves 600–700 users annually and houses an unparalleled collection of state-of-the-art capabilities, including a supercomputer and over 60 major instruments, providing integrated experimental and computational resources for discovery and technological innovation in the

environmental molecular sciences. EMSL also contributes to systems biology by providing leading edge capabilities in proteomics.

**Benefits**

BER science continues to have broad benefits for society and for science. BER's long history of biological discovery has improved human health, advanced scientific discovery, and revolutionized the field of biology. Decades of biological research have led to the development of dosimeters to monitor exposure to radiation and radioisotopes used in tens of millions of medical diagnostic procedures annually. From research to understand the health effects of exposure to radiation we learned of the sensitivity of embryos to radiation, developed assays using mice and the bacteria to quantify the mutagenic potential of radiation and chemicals, and discovered the genes and mechanisms responsible for the repair of damaged DNA.

Perhaps the most revolutionizing event was BER's initiation of the Human Genome Project. Built on the strength in technology development at DOE's national laboratories, the Human Genome Project led to the determination of the complete DNA sequence of the human genome by teams of scientist in the public and private sectors from around the world, information that has provided unprecedented opportunities for discovering and understanding fundamental principles of life. BER carried this new capability to rapidly sequence an organism's complete genome to the fields of microbial and plant biology with an emphasis on organisms with energy and environmental relevance. High throughput technologies for genome sequencing have led to the discovery of novel microorganisms with unanticipated biotechnological capabilities and provided new insights into a variety of plants including trees, legumes and grasses. The ability to study an organism beginning with its DNA sequence has provided unprecedented understanding of fundamental biological processes from the production of proteins to the control of groups of genes linked in a biochemical pathway to the genetic basis for interactions of organisms in complex ecosystems.

Early DOE studies to understand the fate of radioactive fallout on land and in the oceans also had broad impacts, leading to the development of modern ecology and oceanography, tools to understand the intricacies of Earth's climate system, and modeling capabilities for predicting future climate. Our growing understanding of the climate system and our ability to more accurately predict future climate are essential to plan for future energy needs, water resources, and land use. BER research provides new understanding of the biological, physical, and chemical mechanisms responsible for the natural sequestration of carbon dioxide, a key greenhouse gas, in terrestrial ecosystems. This knowledge is useful in understanding the impacts of land use and land management decisions on carbon release or storage from various ecosystems. Through hypothesis-driven research in both laboratories and the field, BER research has revealed new biogeochemical processes that influence the fate and transport of contaminants from a legacy of weapons production.

**Program Planning and Management**

BER uses broad input from scientific workshops or external reviews, such as those performed by the National Academies, to identify current and future scientific and technical needs and challenges in current national and international research efforts. BER also receives advice from the Biological and Environmental Research Advisory Committee (BERAC) on the management of its research programs (through Committee of Visitor [COV] reviews), on the direction and focus of its research programs, and on strategies for long-term planning and development of its research activities. A key focus of BERAC activities is to identify the greatest scientific challenges in biological, climate, and environmental systems science that BER should address in the long term (20-year horizon), and how BER should be positioned to address those challenges; the continued or new fields of BER-relevant science that DOE will need to achieve its future mission challenges; and the future scientific and technical advances needed to underpin BER's complex systems science.

The BER program is coordinated with activities of other federal organizations supporting or conducting complementary research, e.g., the National Science Foundation (NSF), National Aeronautics and Space Administration (NASA), Department of Commerce/National Oceanic and Atmospheric Administration (NOAA), Environmental Protection Agency (EPA), Nuclear Regulatory Commission (NRC), Department of Agriculture (USDA), National Institutes of Health (NIH), Department of State (DOS), and Department of Defense (DOD). BER Climate Change Research is coordinated with the U.S. Global Change Research Program, an interagency program codified by Public Law 101–606 and involving thirteen federal agencies and departments, and the Climate Change Science Program.

BERAC conducts reviews of BER subprograms by COVs every three years. Results of these reviews and BER responses are posted on the BERAC website[a]. Every three years, BER also conducts consolidated onsite merit, operational, management, and safety reviews of each of its user facilities, the Atmospheric Radiation Measurement Climate Research Facilities, the Joint Genome Institute, and the Environmental Molecular Sciences Laboratory. Results of these reviews are used to address management, scientific, operational, and safety deficiencies.

BER supports research at universities, research institutes, private companies, and DOE national laboratories. All BER-supported research undergoes regular peer review and merit evaluation based on procedures established in 10 CFR 605 for the external grant program and using a similar process for research at the national laboratories.

## Basic and Applied R&D Coordination

BER research underpins the needs of DOE's energy and environmental missions. Fundamental research on microbes and plants to understand their biochemical pathways and the genetic mechanisms that control their interactions and behavior provide knowledge needed by DOE's Office of Energy Efficiency and Renewable Energy (and the U.S. Department of Agriculture) about new bioenergy crops and bioenergy production facilities that are cost effective and sustainable. BER research on the behavior and interactions of contaminants in the subsurface environment provides knowledge needed by DOE's Office of Environmental Management to develop new strategies for the remediation of weapons-related contaminants at DOE sites and by DOE's Office of Legacy Management to develop tools for monitoring the long-term status of contaminants at cleanup sites. Knowledge of the subsurface environment as a complete system will also be useful to the DOE Office of Fossil Energy in their efforts to predict the long-term behavior of carbon dioxide injected underground for long-term storage. Finally, BER research to understand Earth's climate system and to predict future climate and climate change is needed by DOE's Office of Policy and International Affairs as it develops strategies for our Nation's future energy needs and control of greenhouse gas emissions.

## Budget Overview

BER's budget strategy is based on four mission priorities: understanding complex biological, climatic, and environmental systems across spatial and temporal scales; exploring the frontiers of genome-enabled biology; discovering the physical, chemical, and biological drivers of climate change; and seeking the molecular determinants of environmental sustainability and stewardship. The BER scientific user facilities are key to supporting these mission priorities.

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[a] Http://www.science.doe.gov/ober/berac.html and http://www.science.doe.gov/SC-2/Committee_of_Visitor.htm

- Genomic science research, including the DOE Bioenergy Research Centers, will advance our understanding of how plant and microbial system functions are specified by genome organization, expression, and regulation. This includes developing genomic, analytical, and computational approaches to study the structure, interdependence, and function of microbial communities and the identification of plant traits for improved bioenergy production or carbon sequestration. The JGI facility operation will continue to support sequencing needs of the Genomic Science program, especially the Bioenergy Research Centers. JGI activities will reflect the steady increase in production DNA sequencing as well as the resulting need for high-throughput, complex genome annotation and analysis.
- Atmospheric System Research will improve understanding and quantification of the role of aerosols and clouds on climate change. Research will be expanded to examine clouds and aerosols in different climatic regions using data from new Atmospheric Radiation Measurement (ARM) sites and lab studies. Results will be used to evaluate and improve performance of regional and global climate models. The new ARM sites and lab studies will support research in locations with different types of clouds, atmospheric conditions, and aerosol loadings to better address major outstanding questions in climate change research (clouds and aerosols).
- Climate and Earth System Modeling will establish a climate modeling center with Advanced Scientific Computing Research. This activity will enhance development, robustness, and resolution of climate models through integration of climate research with DOE Leadership Computing Facilities. High-resolution regional climate simulations will be developed to assess regional and national implications of climate change on human systems and infrastructure, especially energy demand, production, and supply, such as biofuel feedstock production.
- Environmental System Science will initiate an additional large-scale, manipulative experiment in a major terrestrial ecosystem to improve understanding of the impacts of climate change on ecosystem structure and function. Research will be expanded to improve understanding of the role of terrestrial ecosystems as sources and sinks of greenhouse gases. Research will focus on the role of natural processes that control terrestrial carbon sequestration and how those processes might be managed to enhance carbon sequestration in terrestrial ecosystems.
- Subsurface Biogeochemical Research will support basic research on the fate and transport of contaminants in the subsurface. This research addresses unique physical, chemical, and biological processes controlling the flux of contaminants across and within the root zone of soils and the flux of contaminants to surface water bodies. Processes in these critical zones influence fluxes of carbon and key nutrients between the atmosphere and terrestrial biosphere.
- The EMSL equipment refresh will continue to keep EMSL at the state of the art, including enhancement of leading capabilities in proteomics and advanced magnetic resonance. Integration of experimentation and computation will be encouraged by replacing the third generation high performance computing system with two or more systems having architectures appropriate to specific areas of science. A suite of integrated imaging capabilities (advanced data processing, image correlation, and remote operational capabilities) will be developed to better understand biological transformations and energy and materials transport in complex environments and to support systems biology research, particularly proteomics.

### Significant Program Shifts

The BER program has been restructured to combine and integrate climate and environmental science in the Climate and Environmental Sciences subprogram and to define common, integrating themes for life and medical sciences in a Biological Systems Science subprogram. This new budget structure aligns with the BER science mission and increases management efficiency and balance. The outcome will be improved management of BER investments, better integration across the BER portfolio, and improved communication of BER science within DOE, and to the Administration, Congress, the scientific community and the public.

**Strategic and GPRA Unit Program Goals**

The BER program has one Government Performance and Results Act (GPRA) Unit Program Goal which contributes to Strategic Goals 3.1 and 3.2 in the "goal cascade":

- GPRA Unit Program Goal 03.1/2.48.00: Harness the Power of Our Living World—Provide the biological and environmental discoveries necessary to clean and protect our environment, offer new energy alternatives, and facilitate the entrainment of physical sciences advances in the biomedical field.

**Contribution to GPRA Unit Program Goal 03.1/2.48.00, Harness the Power of Our Living World**

BER contributes to this goal by advancing fundamental world-class, merit-reviewed systems research in genomics, proteomics, climate change, environmental remediation, radiobiology, and imaging instrumentation. Discoveries at these scientific frontiers will bring revolutionary and unconventional solutions to some of our most pressing and expensive challenges in energy and the environment.

We intend to understand how living organisms interact with and respond to their environments to be able to use biology to produce clean energy, remove excess carbon dioxide from the atmosphere, and help clean up the environment. Our understanding of the causes and consequences of regional and global climate change and our ability to predict climate over decades to centuries at regional to global scales enables development of science-based solutions to minimize the potential adverse impacts of climate change and to better plan for our Nation's future energy needs and resource use. Understanding the biological effects of low doses of radiation can lead to the development of science-based health risk policy to better protect workers and citizens. Understanding the fate and transport of environmental contaminants can lead to improved decision making as well as the discovery of innovative approaches to remediate and monitor the environment.

BER radiochemistry and advanced instrumentation research seeks to develop new technologies for imaging and sensing applications and for high-throughput characterization and analysis in real time and at multiple spatial scales to enable progress in BER missions in bioenergy, subsurface science, and climate change research. BER research will be completed for development of an artificial retina that will enable the blind to see.

The BER research program capitalizes on the national laboratories' resources and expertise in biological, chemical, physical, and computational sciences, and on their sophisticated instrumentation (e.g., neutron and light sources, mass spectroscopy, high field magnets, lasers, and supercomputers). This research is coordinated with and complementary to other Federal programs.

In addition, BER operates reliable, scientific facilities to serve thousands of researchers at universities, national laboratories, and private institutions from all over the world. These include structural biology research beam lines at the synchrotron light sources and neutron sources; the William R. Wiley Environmental Molecular Sciences Laboratory (EMSL) (including the Molecular Sciences Computing Facility) which provides 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 Joint Genome Institute (JGI) for high-throughput DNA sequencing of non-medical microbes and plant targets; and the Atmospheric Radiation Measurement (ARM) Climate Research Facility

(ACRF) for addressing the two major uncertainties in climate change research, the impact of clouds and aerosols on the radiative budget.

The following indicators establish specific long-term goals in Scientific Advancement that the BER program is committed to, and against which progress can be measured.

**Biological Systems Science**

- Genomic Science: Provide the fundamental scientific understanding of plants and microbes necessary to develop new robust and transformational basic research strategies for producing biofuels, cleaning up waste, and sequestering carbon.
- Medical Applications: Develop intelligent biomimetic electronics that can both sense and correctly stimulate the nervous system.

**Climate and Environmental Sciences**

- Climate Science: Deliver improved scientific data and models about the potential response of the Earth's climate and terrestrial biosphere to increased greenhouse gas levels for policy makers to determine safe levels of greenhouse gases in the atmosphere.
- Subsurface Biogeochemical Research: Provide sufficient scientific understanding such that DOE sites would be able to incorporate coupled physical, chemical, and biological processes into decision making for environmental remediation and long-term stewardship.

**BER Facilities**

- Facilities: Manage facilities operations to the highest standards of overall performance using merit evaluation with independent peer review.

## Annual Performance Results and Targets

| FY 2005 Results | FY 2006 Results | FY 2007 Results | FY 2008 Results | FY 2009 Targets | FY 2010 Targets |
|---|---|---|---|---|---|
| GPRA Unit Program Goal 03.1/2.47.00 (Harness the Power of Our Living World) | | | | | |
| Biological Systems Science | | | | | |
| Genomic Science | | | | | |
| Increase the rate of DNA sequencing: Number (in billions) of base pairs of high quality (less than one error in 10,000 bases) DNA microbial and model organism genome sequence produced annually. FY 2005 at least 28 billion base pairs will be sequenced. [Met Goal] | Increase the rate of DNA sequencing: Number (in billions) of base pairs of high quality (less than one error in 10,000 bases) DNA microbial and model organism genome sequence produced annually. FY 2006 at least 30 billion base pairs will be sequenced. [Met Goal] | Increase the rate and decrease the cost of DNA sequencing – Cost reductions will increase the number of high quality base pairs determined (less than one error in 10,000 bases) by 25% from the FY 2006 target of 582 base pairs per dollar to 781 base pairs per dollar. [Met Goal] | Increase the rate and decrease the cost of DNA sequencing—Increase by 10% the number (in billions) of high quality (less than one error in 10,000) bases of DNA from microbial and model organism genomes sequenced the previous year, and decrease by 10% the cost (base pair/dollar) to produce these base pairs from the previous year's actual results. FY 2008: 42.8 billion base pairs and 785 base pairs per dollar (based on the FY 2007 actual of 38.95 billion base pairs, and JGI achieving 714 billion base pairs per dollar.) [Met Goal] | Increase the rate and decrease the cost of DNA sequencing—Increase by 10% the number (in billions) of high quality (less than one error in 10,000) bases of DNA from microbial and model organism genomes sequenced the previous year, and decrease by 10% the cost (base pairs per dollar) to produce these base pairs from the previous year's actual results. FY 2009: 253 billion base pairs and 4600 base pairs per dollar (based on FY2008 actual of 125.5 Giga base pairs, and achieving 2350 base pairs per dollar.) | Increase the rate and decrease the cost of DNA sequencing—Increase by 10% the number (in billions) of high quality (less than one error in 10,000) bases of DNA from microbial and model organism genomes sequenced the previous year, and decrease by 10% the cost (base pairs per dollar) to produce these base pairs from the previous year's (FY 2009) actual results. |
| Medical Applications | | | | | |
| Advance blind patient sight: Complete testing on a 60 microelectrode array artificial retina and insert prototype device into a blind patient. [Goal Not Met] | Advance blind patient sight: Begin testing of prototypes for 256 microelectrode array artificial retina. [Met Goal] | Advance blind patient sight: complete design and construction of final 256 electrode array. Begin in vitro testing and non-stimulating testing in animals. [Met Goal] | Advance blind patient sight: Complete in vitro testing of 256 electrode array and continue animal studies of final design 256 electrode array. [Met Goal ] | Advance blind patient sight: Complete development of entire 256 electrode implantable device. | Advance blind patient sight: Complete final in vitro and in vivo studies of entire 256 electrode implantable device. |

| FY 2005 Results | FY 2006 Results | FY 2007 Results | FY 2008 Results | FY 2009 Targets | FY 2010 Targets |
|---|---|---|---|---|---|
| Climate and Environmental Sciences | | | | | |
| Climate Science | | | | | |
| Improve climate models: Implement a model test bed system to incorporate climate data rapidly into climate models to allow testing of the performance of sub-models (e.g., cloud resolving module) and model parameters by comparing model simulations with real world data from the ARM sites and satellites. [Met Goal] | Improve climate models: Implement three separate component submodels (an interactive carbon cycle submodel, a secondary sulfur aerosol submodel, and an interactive terrestrial biosphere submodel) within a climate model and conduct 3-4 year duration climate simulation using the fully coupled model. [Met Goal] | Improve climate models: Produce a new continuous time series of retrieved cloud properties at each ARM site and evaluate the extent of agreement between climate model simulations of water vapor concentration and cloud properties and measurements of these quantities on the timescale of 1 to 4 days. [Met Goal] | Improve climate models—Develop a coupled climate model with fully interactive carbon and sulfur cycles, as well as dynamic vegetation to enable simulations of aerosol effects, carbon chemistry, and carbon sequestration by the land surface and oceans and the interactions between the carbon cycle and climate. FY 2008: Report results of decade-long control simulation using geodesic grid coupled climate model and produce new continuous time series of retrieved cloud, aerosol, and dust properties, based on results from the ARM Mobile Facility deployment in Niger, Africa. [Met Goal] | Improve climate models—Develop a coupled climate model with fully interactive carbon and sulfur cycles, as well as dynamic vegetation to enable simulations of aerosol effects, carbon chemistry, and carbon sequestration by the land surface and oceans and the interactions between the carbon cycle and climate. FY 2009: Provide improved climate simulations on subcontinental, regional, and large watershed scales, with an emphasis on improved simulation of precipitation and produce new continuous time series of retrieved cloud, aerosol, and radiation for Arctic region. | Improve climate models—Develop a coupled climate model with fully interactive carbon and sulfur cycles, as well as dynamic vegetation to enable simulations of aerosol effects, carbon chemistry, and carbon sequestration by the land surface and oceans and the interactions between the carbon cycle and climate. FY 2010: Provide a new parameterization for aerosol effects on cloud drizzle for incorporation into atmospheric models. |
| Subsurface Biogeochemical Research | | | | | |
| Perform combined field/laboratory/modeling to determine how to interpret data at widely differing scales: Quantify contaminant immobilization and remobilization by different factors: 1. natural microbial mechanisms; 2. chemical reactions with minerals; and 3. colloid formation. [Met Goal] | Determine scalability of laboratory results in field experiments—Conduct two sets of field experiments to evaluate biological reduction of chromium and uranium by microorganisms and compare the results to laboratory studies to understand the long term fate and transport of these elements in field settings. [Met Goal] | Develop predictive model for contaminant transport that incorporates complex biology, hydrology, and chemistry of the subsurface. Validate model through field tests. [Met Goal] | Determine scalability of laboratory results in field environments—Determine the dominant processes controlling the fate and transport of contaminants in subsurface environments and develop quantitative numerical models to describe contaminant mobility at the field scale. For FY 2008: Identify the critical redox reactions and metabolic pathways involved in the transformation/ sequestration of at least one key DOE contaminant in a field environment. [Met Goal]. | Determine scalability of laboratory results in field environments—Determine the dominant processes controlling the fate and transport of contaminants in subsurface environments and develop quantitative numerical models to describe contaminant mobility at the field scale. For FY 2009: Test geophysical techniques that measure parameters controlling contaminant movement under field conditions in at least two distinct subsurface environments. | Determine scalability of laboratory results in field environments—Determine the dominant processes controlling the fate and transport of contaminants in subsurface environments and develop quantitative numerical models to describe contaminant mobility at the field scale. For FY 2010: Using field experiments and reactive transport models, describe the key processes for subsurface mass transfer of contaminants to inform the development of next generation models. |

| FY 2005 Results | FY 2006 Results | FY 2007 Results | FY 2008 Results | FY 2009 Targets | FY 2010 Targets |
|---|---|---|---|---|---|
| All BER Facilities | | | | | |
| Maintain and operate BER facilities such that achieved operation time is on average greater than 90% of the total scheduled annual operation time. [Met Goal] | Maintain and operate BER facilities (Life Science—PGF and the Mouse facility; Climate Change Research—ARM and FACE; and Environmental Remediation—EMSL) such that achieved operation time is on average greater than 90% of the total scheduled annual operation time for each group of facilities. [Met Goal] | Maintain and operate BER facilities (Life Science—PGF and the Mouse facility; Climate Change Research—ARM and FACE; and Environmental Remediation—EMSL) such that achieved operation time is on average greater than 95% of the total scheduled annual operation time for each group of facilities. [Met Goal] | The achieved operation time of the scientific user facility (Genomic Science—JGI; Climate Science—ACRF; and Subsurface—EMSL) as a percentage of the total scheduled annual operating time is greater than 98%. Milestone met for ACRF and EMSL; JGI was at 94%. This reflects the December shutdown for ergonomic safety. The safety issue has been corrected. [Goal Not Met] | The achieved operation time of the scientific user facility (Genomic Science—JGI; Climate Science—ACRF; and Subsurface—EMSL) as a percentage of the total scheduled annual operating time is greater than 98%. | The achieved operation time of the scientific user facility (Genomic Science— GI; Climate Science—ACRF; and Subsurface —EMSL) as a percentage of the total scheduled annual operating time is greater than 98%. |

**Biological Systems Science**

**Funding Schedule by Activity**[a]

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Biological Systems Science | | | |
| Genomic Science | 164,085 | 169,858 | 165,626 |
| Radiological Sciences | 46,674 | 50,768 | 46,615 |
| Ethical, Legal, and Societal Issues | 5,000 | 5,000 | 5,000 |
| Medical Applications | 8,191 | 8,226 | 8,226 |
| Biological Systems Facilities and Infrastructure | 80,011 | 80,300 | 84,300 |
| SBIR/STTR | — | 8,663 | 8,709 |
| Total, Biological Systems Science | 303,961 | 322,815 | 318,476 |

## Description

Systems biology is the holistic, multidisciplinary study of complex interactions that specify the function an entire biological system—whether single cells or a multicellular organism—rather than the reductionist study of individual components. The Biological Systems Science subprogram focuses on understanding the functional principles that drive living systems, systems ranging in scale from microbes and microbial communities to plants and other whole organisms. These principles require understanding the genomic blueprint that underlies the potential for life processes, the translation of that blueprint into subcellular proteins, metabolites, and cellular architecture, and the organizing principles between these molecules. Questions asked in the subprogram include: *What information is contained in the genome sequence? How is information integrated and processed in a coordinated manner between the different subcellular constituents? What are the key molecular interactions that regulate the overall response of the living system and how can those interactions be understood in a dynamic and predictive way?* The systems biology approaches employed include genome sequencing, proteomics, metabolomics, structural biology, high-resolution imaging and characterization, and integration of the resulting information into predictive computational models of biological systems that can be functionally tested and validated. This coupling between experimentation and modeling of how biological systems receive, process, and respond to signals—from genetic or developmental programs and external cellular or environmental cues—is the systems biology theme for the research supported by this subprogram. These signals can be exchanged between different biological systems, such as in a microbial community within the termite gut or associated with plant roots, and can enable biological systems to probe and respond to their physical environment.

The subprogram supports multidisciplinary research primarily focused on microbial and plant systems, as well as operations of the subprogram's primary research facility, the DOE Joint Genome Institute, and access to structural biology facilities. Support is also provided for research at the interface between the biological and physical sciences, in radiochemistry and instrumentation research, and the proof-of-concept design of an implantable, artificial sensor.

[a] This table shows the FY 2008 and FY 2009 funding in the new (comparable) budget structure to assist in comparing year-to-year funding trends. A cross-walk of the new and old structure is provided at the end of this chapter, describing in detail the modification to the budget structure.

**Selected FY 2008 Accomplishments**

- Systems biology approaches have enabled scientists to determine how a newly-discovered microbial species can exist by itself in complete darkness nearly two miles below the Earth's surface. Examination of its genome reveals the presence of everything needed for the organism to sustain an independent existence and reproduce, including the ability to incorporate the elements necessary for life from inorganic sources, move freely, and protect itself from viruses, harsh conditions, and nutrient-poor periods. Results of these studies have not only provided new insights into the mechanism that microbes use to survive under challenging environmental conditions, but also provide clues on how to manipulate them for bioremediation of contaminants.
- The DOE Bioenergy Research Centers have developed a variety of new methods that can overcome the resistance of plant biomass to breakdown and conversion into biofuels. These methods range from using ionic liquids to break apart linkages between biomass molecules such as cellulose, hemicellulose, and lignin, to developing an integrated high throughput characterization screen that allows the rapid identification and correlation of the chemical, structural, and genetic features of plant biomass.
- The DOE Joint Genome Institute (JGI) contributed significant achievements in genome sequencing and analysis in support of the DOE missions. Major accomplishments include: completing a draft assembly of the one billion nucleotide soybean genome—roughly one-third the size of the human genome—containing as many as 66,000 genes that hold the keys to edible protein production, biodiesel fuel, and carbon-nitrogen nutrient cycling in agricultural soils; and sequencing the genome of the photosynthetic alga, *Chlamydomonas reinhardtii*, revealing fundamental mechanisms for absorbing sunlight and coupling carbon dioxide and water to build cell structure and drive carbon metabolism.
- Scientists have developed a way to synthesize a whole new class of radiotracers, compounds that can be tracked by PET scanners to monitor the movement and interactions of a wide range of chemicals in biological and environmental systems. This new methodology uses a commercially available, inexpensive compound (trimethylamine-N-oxide) for rapid, efficient conversion of carbon-11-labeled methyl iodide to carbon-11-labeled formaldehyde, a useful reagent central to synthesis of a wide range of radiolabeled compounds to probe biological processes.

## Detailed Justification

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| **Genomic Science** | **164,085** | **169,858** | **165,626** |
| ▪ **Foundational Genomics Research** | **33,422** | **38,267** | **33,216** |

The Foundational Genomics Research activity supports fundamental research on microbes and plants, with an emphasis on understanding biological systems across multiple scales of organization, ranging from subcellular protein-protein interactions to complex microbial community structures. At the subcellular level, this research focuses on the characterization and spatial organization of cellular components and the regulatory and metabolic networks of microbes and plants. It investigates how cells are able to balance dynamic needs for synthesis, assembly, and turnover of cellular machinery in response to changing signals from the environment. Foundational genomic research will increasingly focus on understanding how different organisms

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |

interact within a biological or environmental system to provide unique functions through mechanisms such as commensal nutrient flow or horizontal gene transfer. These systems-level capabilities allow a broad diversity of functions, ranging from microbial respiration and speciation of soil minerals to nutrient uptake and cell-cell communication, as well as a testable framework for development of genome-based models for systems biology. Research also includes the development of new biotechnological approaches specifically designed for systems biology, including methods to measure metabolites, proteins, and expressed genes for microbial communities, to provide real-time insight into actively occurring processes. The emphasis is on research that employs advanced molecular and computational biology approaches enabled by genome sequencing and emphasizes multidisciplinary efforts combining expertise in microbiology, plant biology, chemistry, biophysics, bioinformatics, metabolic engineering, and other fields.

In FY 2010, research is supported to advance the understanding of how complex biological system function is specified by genome organization, expression, and regulation. This includes developing genomic and analytical technologies to study the structure, interdependence, and function of microbial communities. Capital equipment investments to support the program’s advanced imaging and analytic requirements for multifactorial measurements of genome-directed cellular function are completed in FY 2009.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **Genomics Analysis and Validation** | **10,521** | **10,000** | **10,000** |

The Genomics Analysis and Validation activity develops the tools and resources needed to fully exploit the information contained in complete DNA sequences from microbes and plants for bioenergy, carbon sequestration, and bioremediation applications. This activity supports development of new strategies and tools capable of high-throughput, genome-wide experimental and analytic approaches for complex biological systems.

New high-throughput approaches for analyzing gene regulation and function, automated annotation tools for predicting genes and protein function from DNA sequence, and tools for identifying dynamic genome interactions within a biological or environmental system are essential for uncovering emergent properties of interacting genes. The ability to predict the function of an individual gene and sets of genes is essential for design and validation of strategies for bioenergy production, enhanced carbon sequestration, or environmental remediation.

In FY 2010, research supports the experimental validation and improvement of genome-scale annotation and gene models in microbes, plants, and complex biological systems.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **Metabolic Synthesis and Conversion** | **41,297** | **42,127** | **39,127** |

This activity focuses on understanding biological pathway composition and regulation to effect conversion of carbon from simple precursor forms into advanced biomolecules. Fundamental research focuses on understanding carbon uptake, fixation and storage in plants and soil microbes, strongly leveraging the increasing availability of information from whole organism genomes and community metagenomes. Research will also focus on understanding the role that microbial communities or plant-microbe associations play in the transfer of carbon between the roots and the soil, to identify strategies that would lead to increased carbon storage in the rhizosphere and surrounding soil. Genome-based knowledge of metabolic functions and regulatory networks in microbial systems, plants, and plant-microbe associations

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |

can enable strategies to increase biomass formation for conversion into advanced biofuels or to increase the sequestration of carbon in terrestrial ecosystems.

While this activity draws upon the foundational research and technology development within the broader Genomic Sciences portfolio, it will specifically address challenges unique to advancing biofuels through understanding the metabolic conversion of simple sugars to ethanol and hydrogen. This will lead to improved understanding of environmental variables governing partitioning of energy precursors into different biomass, respiration, or energy producing pathways, or fixation into recalcitrant soil or marine carbon forms. Systems biology approaches are supported to understand how plant genomes can specify increased carbon fixation and biomass yield, improved feedstock characteristics, and sustainability.

In FY 2010, funds will continue to support research on carbon storage in plant biomass for conversion into advanced biofuels or carbon sequestration. Funds will also support research focused on the characterization and regulation of carbon and nutrient cycling in plant and microbial systems, from subcellular or root-stem-leaf partitioning to flux within pathways or between networks of interacting organisms within a biological system. Pilot studies to develop advanced research technologies for imaging of lignocellulose during conversion to cellulosic ethanol or for validation of metabolic pathways during microbial hydrogen production are competed in FY 2009.

| | | | |
|---|---|---|---|
| ▪ **Computational Biosciences** | **3,845** | **4,464** | **8,283** |

Computational models and the necessary algorithmic and computational tools needed to describe the biochemical capabilities of microbial communities or plants are essential to the success of the BER Genomic Sciences activity. The models are needed to integrate diverse data types and data sets—from experiments using genomics, proteomics, and metabolomics—into single models, and they must accurately describe and predict the behavior of metabolic pathways and genetic regulatory networks. A systems biology knowledgebase is an integrated experimental framework for accessing comparing, analyzing, modeling, and testing systems biology data. The extension of capabilities beyond data generation and storage to data retrieval, data access, and cross-database comparative computational modeling forms the basic requirements of a systems biology knowledgebase. This will enable and provide support for progressively more precise and comprehensive predictive modeling of various catalytic and cellular processes, organisms, and communities. The systems biology knowledgebase dimensions and requirements were recently outlined in a community workshop.

A knowledgebase framework is needed to compare and integrate mission critical data and information in a precise and comprehensive manner to develop bioenergy, carbon sequestration, or bioremediation strategies. This activity includes support for ongoing (Scientific Discovery through Advanced Computing) SciDAC research that develops multi-scale and multi-component mathematical and computational tools needed for modeling and analysis of complex data sets, such as mass spectrometry or metabolomics, and to develop predictive metagenomic models of complex microbial communities. The research is closely coordinated with SC's Advanced Scientific Computing Research Program.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |

In FY 2010, funding will support ongoing SciDAC research on the modeling of protein structure and function. Funding is increased to support establishment of a system biology modeling framework, allowing open access to researchers to biological data and analytical tools. The framework will include biological database research and development, new software and algorithm research for interoperability among databases, and will develop and test predictive models for microbial systems of DOE relevance with respect to physiological properties, behavior and whole microbe responses. The framework will enable broad, distributed access to a virtual computational environment, allowing integrated genome-scale modeling and reconstruction, using microbial experimental datasets from genome sequencing, biological networks and metabolic pathways, and transcriptional regulation. The initial primary microbial experimental datasets for integration will be drawn from research conducted at the DOE Bioenergy Research Centers, the Joint Genome Institute, and the Environmental Molecular Sciences Laboratory.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **Bioenergy Research Centers** | **75,000** | **75,000** | **75,000** |

In 2007, BER established three Bioenergy Research Centers to accelerate the transformational breakthroughs in basic science needed for the development of cost-effective technologies to make production of cellulosic (plant-fiber based) biofuels commercially viable on a national scale.

The Centers each represent a multidisciplinary, multi-institutional partnership between universities, national laboratories, and the private sector. The Centers take scientific approaches that are complementary and synergistic. Areas of fundamental research include the identification, characterization, and systems-level regulation of genetic traits for cell wall composition of model plants such as Arabidopsis and rice, for which detailed genome sequence and phenotypic information are available, as well as second-generation bioenergy crops such as poplar and switchgrass for which we possess more limited genomic resources. Other studies focus on understanding the metabolic pathways in individual microbes or microbial consortia that carry out efficient degradation of cell wall material and conversion into ethanol, hydrocarbons, diesel, and even jet fuel. The Centers also focus on modeling structure-function relationships in enzymes and proteins important in the synthesis, turnover, and remodeling of plant cell wall biomass, as well as subsequent metabolic and enzymatic conversion.

The first year progress of each center was evaluated by an on-site review of science and management activities and progress against stated milestones. The external review teams were comprised of scientists from universities and a DOE National Laboratory, with expertise in systems biology, microbial physiology and genetics, plant genomics and bioinformatics, genomic database management and informatics, and analytical chemistry. All three centers received highly favorable evaluations of progress against milestones and for the planned science programs.

The Great Lakes Bioenergy Research Center (GLBRC), led by the University of Wisconsin in partnership with Michigan State University, milestones:

- Completion of start-up activities and achievement of full operational status.
- Identification of key structural carbohydrate biosynthesis genes in model plant systems.
- Complete proof-of-concept research for oil production in plant vegetative tissues.
- Establishment of a cell wall analytical platform.

| (dollars in thousands) | | |
|---|---|---|
| FY 2008 | FY 2009 | FY 2010 |

- Identification of a new catalytic processes for direct conversion of lignocellulose to biofuel precursor molecules.
- Establishment of field experiments and development of methodology for data collection and analysis for sustainable biofuel production.

The Joint BioEnergy Institute (JBEI), led by Lawrence Berkeley National Laboratory, milestones:

- Completion of start-up activities and achievement of full operational status.
- Identification and selection of key candidate genes for controlling cell wall synthesis and composition.
- Development of new high-throughput assays for biomass characterization, pretreatment, and enzymatic deconstruction.
- Complete characterization of one targeted plant feedstock under ionic liquid pretreatment conditions.
- Initial metabolic profiling of microbial community samples and selection of key candidate novel cellulase enzymes.
- Identification and prioritization of candidates for metabolic engineering of advanced hydrocarbon biofuels.

The BioEnergy Science Center (BESC), led by Oak Ridge National Laboratory, milestones:

- Completion of start-up activities and achievement of full operational status.
- Establishment of preliminary models of cell wall biosynthesis pathways in poplar and switchgrass.
- Establishment of full high-throughput pipelines for plant transformation, biomass pretreatment and enzyme deconstruction analysis.
- High-throughput screening of environmental diversity poplar samples and identification of modified cell wall composition.
- Identification of over 20 new components in the cellulosome from transcriptomics and proteomic studies.
- Completion of initial round of microbial sampling from targeted diverse environments for new biocatalyst discovery.

The Centers are using the advanced, genomics-based techniques of modern systems biology to re-engineer both plants and microbes for more efficient biologically-based conversion of plant fiber into carbon-neutral biofuels. This capability addresses critical DOE mission needs in the area of secure and sustainable bioenergy production.

In FY 2010, funds will support the continued work of the three DOE Bioenergy Research Centers to pursue fundamental research focused on improving breakdown of plant biomass, discovery and bioengineering of new microbes and enzymes capable of degrading lignocellulose, and conversion of cellulose-derived sugars to carbon-neutral biofuels.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| **Radiological Sciences** | **46,674** | **50,768** | **46,615** |
| ▪ **Radiochemistry and Imaging Instrumentation** | **21,789** | **22,841** | **20,688** |

The activity supports fundamental research in radiochemistry and radiotracer development activities that include development of new methodologies for real-time, high-resolution imaging of dynamic biological processes in energy- and environment-relevant contexts. Radionuclide imaging continues to stand out as a singular tool for studying living organisms in a manner that is highly quantitative, three dimensional, temporally dynamic, and non-perturbative of the natural biochemical processes under study.

Radiotracer imaging methods provide new opportunities for quantitative measurement of in situ chemical reactions in living systems. The activity encompasses applications of new innovative technologies for biological systems with primary benefits for DOE mission needs while also providing fundamental research and tool development that may translate to nuclear medicine diagnostic and therapeutic research.

In FY 2010, funds will support improvements in synthetic radiochemical methods, new radiotracer design, and the development of multimodality tracers. These new approaches will be combined with advanced imaging instrumentation and detectors, to expand the opportunities for non-perturbative study of microbial and plant metabolism, and for tracking dynamic processes in the environment. Multi-year activities initiated in FY 2009 in development of new radiochemistry synthetic and detection methods will continue in FY 2010. Pilot activities initiated in FY 2008 for the development and use of innovative radiotracer chemistry or instrumentation technologies will be completed in FY 2010.

| | | | |
|---|---|---|---|
| ▪ **Radiobiology** | **24,885** | **27,927** | **25,927** |

The Radiobiology activity supports research that will help determine health risks from exposures to low levels of ionizing radiation, information critical to adequately and appropriately protect radiation workers and the general public. Research investigations include a number of critical biological phenomena induced by low dose exposure including adaptive responses, bystander effects, genomic instability, and genetic susceptibility. This activity includes support for development of systems genetic strategies, including the role of epigenetics in integrated gene function and response of biological systems to environmental conditions.

This activity will provide a scientific basis for informed decisions regarding remediation of contaminated DOE sites and for determining acceptable levels of human health protection, both for cleanup workers and the public in the most cost-effective manner.

In FY 2010, funds will support the development of models that integrate responses to low dose radiation at the tissue or whole organism level with available epidemiological data to contribute to developing safe and appropriate radiation protection standards and the development of systems genetic strategies for integrated gene function and response to the environment. Funds are decreased to reflect the full transfer of mouse stocks at the Laboratory of Comparative and Functional Genomics (the Mouse House) to the University of North Carolina. Research on the low dose radiation response in individual cell types is decreased in FY 2010.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| | (dollars in thousands) | | |
| **Ethical, Legal, and Societal Issues** | **5,000** | **5,000** | **5,000** |

ELSI research supports activities applicable to Office of Science interests in bioenergy, synthetic biology, and nanotechnology, including exploration and communication of the societal implications arising from these programs. The ecological and environmental impacts of nanoparticles resulting from nanotechnology applied to energy technologies will be studied. The research will be coordinated across the Office of Science and with other relevant Federal agencies and offices, such as EPA, NSF and OSTP.

The ELSI program takes a proactive stance to anticipate societal benefits and implications of science and contributes to the informed choices society makes to implement scientific knowledge.

In FY 2010, funding is provided to support explorations of the potential societal implications arising from scientific research in areas of systems microbiology, synthetic genomics, sustainable bioenergy crop production, and nanotechnology in the environment.

| | | | |
|---|---|---|---|
| **Medical Applications** | **8,191** | **8,226** | **8,226** |

Research continues to utilize resources of the national laboratories in material sciences, engineering, microfabrication, and microengineering to develop unique neuroprostheses and to continue development of an artificial retina to restore sight to the blind. DOE's goal for the artificial retina project is to develop the technology underpinning the ultimate fabrication of a 1,000+ electrode intraocular device that will allow a blind person to read large print, recognize faces, and move around without difficulty.

The Artificial Retina activity enables scientists to work together across disciplines and promotes scientific and technological innovation at the interface between biology and the physical sciences. The results will benefit not only human health but also other DOE-relevant areas such as sensor development for environmental monitoring.

In FY 2010, BER will support final testing of a completely fabricated 240+ electrode retinal device as a basis for fabrication of the 1,000+ electrode device. The DOE-funded phase of this effort will be completed in FY 2010.

| | | | |
|---|---|---|---|
| **Biological Systems Facilities and Infrastructure** | **80,011** | **80,300** | **84,300** |
| ▪ **Structural Biology Infrastructure** | **15,446** | **15,300** | **15,300** |

The Structural Biology Infrastructure activity continues to develop and support access to beamlines and instrumentation at DOE's national user facilities for the Nation's structural biologists. BER coordinates, with the NIH and NSF, the management and maintenance of 22 experimental stations at several DOE synchrotrons (Advanced Photon Source [APS], Advanced Light Source [ALS], and Stanford Synchrotron Radiation Laboratory [SSRL]) and neutron sources (High Flux Isotope Reactor [HFIR] and Los Alamos Neutron Science Center [LANSCE]). User statistics for all BER structural biology user facilities are included in the Basic Energy Sciences (BES) facility user reports. BER continually assesses the quality of the instrumentation at its experimental stations and supports upgrades to install the most effective instrumentation for taking full advantage of the facility capabilities as they are improved by DOE.

The Structural Biology infrastructure enables a broad user community to conduct the high-resolution study of biological molecules involved in cellular architecture, biocatalysis, environmental sensing, and carbon capture. It advances and promotes scientific and technological innovation in support of the DOE mission.

In FY 2010 funds will continue to support biological community access to structural biology beamlines and instrumentation at DOE national user facilities.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **Joint Genome Institute** | **64,565** | **65,000** | **69,000** |

The Joint Genome Institute (JGI) is the only federally funded large genome center focusing on genome discovery and analysis in plants and microbes for energy and environmental applications. This unique status has enabled it to contribute valuable information through the large-scale genome sequencing of bioenergy crops such as sorghum, maize, poplar, and soybean, as well as targeted sequencing of gene expression sets for switchgrass, cotton, wheat, and conifers. The JGI provides the genomic blueprint which is the basis for systems biology of plants and environmental microbes. Through the development of genome assembly algorithms, tools for comparative gene and pathway analysis, and systems-level integration of data from multiple sequencing technology and functional genomic platforms, the JGI has enabled researchers and plant breeders to identify key traits and genes for specific bioenergy applications or environmental conditions. In addition to a broad reference set of laboratory cultured microbes, the JGI has pioneered approaches for sequencing uncultured, environmental microbial isolates and microbial communities. These metagenomic capabilities will eventually allow elucidation of the functional potential of all the biological organisms that comprise a specific environmental system.

The JGI provides DOE mission-relevant genome sequencing, genome data acquisition, and genome analysis to the broad scientific user community, DOE national laboratories, and the Bioenergy Research Centers. This suite of high-throughput tools, technologies, and comparative analytical capabilities serve as a discovery platform for understanding the organization and function of complex genomes. This genomic-level understanding is vital to the predictive design and engineering of microbial and plant systems for mission capabilities in bioenergy, carbon cycling and biosequestration, and environmental remediation and stewardship.

In FY 2010, funding will continue to support user community access and DOE Bioenergy Research Center to integrative large-scale genome data acquisition and analysis of biological systems at the JGI. Funding is increased to focus on metagenome expression and sequencing of environmental microbial communities or the plant-microbe rhizosphere, as well as improved genome annotation and functional analysis and verification of genome-scale models.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |

| | FY 2008 | FY 2009 (estimated) | FY 2010 |
|---|---|---|---|
| Achieved Operating Hours | 7,704 | N/A | N/A |
| Planned Operating Hours | 8,400 | 8,400 | 8,400 |
| Optimal hours | 8,400 | 8,400 | 8,400 |
| Percent of Optimal Hours | 92% | 100% | 100% |
| Unscheduled Downtime | 696 | N/A | N/A |
| Number of Users[a] | 679 | 780 | 940 |

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **SBIR/STTR** | **—** | **8,663** | **8,709** |

In FY 2008, $6,947,000 and $786,000 were transferred to the SBIR and STTR programs, respectively. FY 2009 and FY 2010 amounts shown are the estimated requirements for continuation of the congressionally mandated SBIR and STTR programs.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **Total, Biological Systems Science** | **303,961** | **322,815** | **318,476** |

## Explanation of Funding Changes

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| **Genomic Science** | |
| ▪ **Foundational Genomics Research** | |
| Investments in capital equipment for the program's advanced imaging and analytic requirements for multifactorial measurements of genome-directed cellular function are completed in FY 2009. | -5,051 |
| ▪ **Metabolic Synthesis and Conversion** | |
| Pilot studies to develop advanced research technologies for imaging of lignocellulose during conversion to cellulosic ethanol or for validation of metabolic pathways during microbial hydrogen production are completed in FY 2009. | -3,000 |
| ▪ **Computational Biosciences** | |
| Funding is increased to support establishment of a systems biology computational framework to provide multi-scale data analysis tools for biological networks and metabolic pathways. Research will initially focus on integrated genome-scale | +3,819 |

[a] All JGI users are remote. Primary users are individuals associated with approved projects being conducted at the JGI in a reporting period. Each user is counted once per year regardless of how many proposals their name may be associated with. Different users may utilize vastly differing levels of JGI resources.

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| reconstruction of metabolic and transcriptional regulatory networks in microbial systems of DOE relevance. Initial targets will include experimental datasets from the DOE Bioenergy Research Centers, the Joint Genome Institute, and the Environmental Molecular Sciences Laboratory, leading to predictive modeling of physiological properties, behavior and whole microbe responses. | |
| **Total, Genomic Science** | **-4,232** |
| **Radiological Sciences** | |
| ▪ **Radiochemistry and Imaging Instrumentation** | |
| Multi-year activities in the development of new radiochemistry synthetic and detection methods will continue in FY 2010. Pilot activities initiated in FY 2008 for the development and use of innovative radiotracer chemistry or instrumentation technologies will be completed in FY 2010. | -2,153 |
| ▪ **Radiobiology** | |
| The decrease discontinues research support at the Mouse House with the complete transfer of genetically-defined mouse strains from Oak Ridge National Laboratory to the University of North Carolina. | -2,000 |
| **Total, Radiological Sciences** | **-4,153** |
| **Biological Systems Facilities and Infrastructure** | |
| ▪ **Joint Genome Institute** | |
| Funding is increased for metagenome expression and sequencing of environmental microbial communities or the plant-microbe rhizosphere, as well as improved genome annotation and functional analysis and verification of genome-scale models. | +4,000 |
| **SBIR/STTR** | |
| ▪ SBIR/STTR is increased as research support is enhanced. | +46 |
| **Total Funding Change, Biological Systems Science** | **-4,339** |

**Climate and Environmental Sciences**

**Funding Schedule by Activity**[a]

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Climate and Environmental Sciences | | | |
| Atmospheric System Research | 25,201 | 25,316 | 26,452 |
| Environmental System Science | 77,816 | 79,631 | 82,558 |
| Climate and Earth System Modeling | 35,141 | 72,029 | 69,775 |
| Climate and Environmental Facilities and Infrastructure | 88,944 | 94,450 | 99,479 |
| SBIR/STTR | — | 7,299 | 7,442 |
| Total, Climate and Environmental Sciences | 227,102 | 278,725 | 285,706 |

## Description

The Climate and Environmental Sciences subprogram focuses on a predictive, systems-level understanding of the fundamental science associated with climate change and DOE's environmental challenges—both key to support the DOE mission. The subprogram supports an integrated portfolio of research ranging from molecular to field scale studies with emphasis on the use of advanced computer models and multidisciplinary experimentation. Climate and Environmental Sciences supports three research activities and two national scientific user facilities. The Atmospheric System Research activity seeks to resolve the two major areas of uncertainty in climate change projections: the role of clouds and the effects of aerosol emissions on the atmospheric radiation balance. Climate and Earth System Modeling focuses on development, evaluation, and use of large scale climate change models to determine the impacts, and possible mitigation, of climate change. The Environmental System Science activity provides scientific understanding of the effects of climate change on terrestrial ecosystems, the role of terrestrial ecosystems in global carbon cycling, and the role of subsurface biogeochemical processes on the fate and transport of DOE-relevant contaminants including heavy metals and radionuclides. Two scientific user facilities—the Atmospheric Radiation Measurement (ARM) Climate Research Facility (ACRF) and the Environmental Molecular Sciences Laboratory (EMSL)—provide the broad scientific community with technical capabilities, scientific expertise, and unique information to facilitate science in areas of importance to DOE.

Climate change research involves advances in the comprehensive understanding of the basic chemical, physical, and biological processes of the Earth's atmosphere, land, and oceans and how these processes may be affected by energy production and use, primarily the emission of carbon dioxide from fossil fuel combustion. The fundamental research is designed to provide the scientific data and understanding that will enable an objective assessment of the potential for, and consequences of, global warming. The research elements are: understanding the quantitative role of atmospheric processes, particularly clouds and aerosols, on the radiation balance of Earth's atmosphere; advancing state-of-the-science models of climate change from regional to global scales for climate change projections; and quantifying effects of

[a] This table shows the FY 2008 and FY 2009 funding in the new (comparable) budget structure to assist in comparing year-to-year funding trends. A cross-walk of the new and old structure is provided at the end of this chapter, describing in detail the modification to the budget structure.

climate change on the terrestrial biosphere and the dynamic role of the terrestrial biosphere in the global carbon cycle. Environmental system science seeks a basic understanding of subsurface biogeochemical processes to predict terrestrial carbon dynamics and storage, and contaminant fate and transport processes. The subsurface biogeochemical fate and transport research advances the fundamental science needed to understand, predict, and mitigate the impacts of environmental contamination from past nuclear weapons production and provides a scientific basis for the long-term stewardship of nuclear waste disposal. Research focuses on understanding the biogeochemical processes that influence and control the environmental mobility of DOE-relevant contaminants in the subsurface and developing the tools and technologies needed to advance subsurface science.

**Selected FY 2008 Accomplishments**

- ACRF data have been used to significantly improve representations of mixed-phase (liquid and ice) clouds in climate models, an ARM science priority, resulting in better climate simulations. These clouds dominate low-level Arctic atmosphere and have a significant impact on the surface energy budget in this climatically important region.
- Scientists have documented climate-related shifts of plant distribution in the mountains of California**.** This study is consistent with the hypothesis that ongoing global warming is expected to shift the geographic distribution of plants as species expand into newly favorable areas and decline in increasingly hostile locations.
- Scientists stimulated the activity of a specific group of microorganisms to successfully reduce the concentration of chromium in groundwater at Hanford. Using the latest genomic science-enabled techniques, researchers were able to correlate shifts in microbial community composition and specific functional genes with decreasing chromium concentrations. These results provide new insights into subsurface microbial ecology and activity that will aid *in situ* bioremediation.

## Detailed Justification

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| **Atmospheric System Research** | **25,201** | **25,316** | **26,452** |

The emphasis for Atmospheric System Research is on understanding the radiation balance from the surface of the Earth to the top of the atmosphere and how this balance is affected by clouds, aerosols, and increases in the concentration of greenhouse gases in the atmosphere. In the presence of clouds and aerosols, the current state of the radiative transfer modeling is inaccurate, limiting our ability to predict future climates with a high degree of confidence.

The Intergovernmental Panel on Climate Change (IPCC) fourth assessment report establishes that cloud simulation is poor in all climate models. With regard to aerosols, the problem is more severe; we are less sure of the magnitude of its forcing on the climate. The research seeks to increase the fidelity of process representations (and interactions among processes) that are needed inputs to the development of the next-generation of climate models, both in the U.S. and internationally.

In FY 2010, research will continue to focus on improving the understanding of the relationship of clouds and radiative transfer processes in the atmosphere and the characterization of aerosol physical, chemical, and optical properties and their effects on the Earth’s energy balance. Research will focus on furthering our understanding of the life cycle of marine boundary layer clouds and their impacts on radiation. Priority aerosol studies include transformations and properties of carbonaceous aerosols,

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |

especially secondary organic aerosols, which are poorly predicted by current atmospheric models. The research will also focus on aerosol processes controlling new particle formation and growth, as well as the properties that affect their activation as droplet and crystal nuclei. Research will use atmospheric measurements from laboratory, ACRF, and other sources in this effort. Research will also be coordinated with Earth System Modeling to quickly and effectively incorporate results into climate models. The additional funds will support development and evaluation of new representations of cloud and aerosol processes for the next generation Earth System Model.

| | | | |
|---|---|---|---|
| **Environmental System Science** | **77,816** | **79,631** | **82,558** |
| ▪ **Terrestrial Ecosystem Science** | **26,005** | **25,913** | **27,913** |

The Terrestrial Ecosystem Science activity develops the scientific understanding of the effects of climate change on terrestrial ecosystems and the role of terrestrial ecosystems in global carbon cycling. The research focuses on determining the effects of climate change on the structure and functioning of terrestrial ecosystems, understanding the processes controlling exchange rate of carbon dioxide between atmosphere and terrestrial biosphere, evaluating terrestrial source-sink mechanisms for atmospheric carbon dioxide, and improving reliability of global carbon cycle models for predicting future atmospheric concentrations of carbon dioxide.

Present correlations between climate and ecosystems do not provide the requisite cause-and-effect understanding needed to forecast effects of future climate changes on terrestrial ecosystems. Experiments involving controlled manipulations of climate factors, and atmospheric carbon dioxide ($CO_2$) concentration, are therefore needed to establish cause-and-effect relationships between climate changes and effects on ecosystems. A significant fraction of the $CO_2$ released to the atmosphere during fossil fuel combustion is taken up by terrestrial ecosystems. However, the impacts of the timing and magnitude of climate change, particularly warming, on the uptake of $CO_2$ by the terrestrial biosphere remains a mystery. The significant sensitivity of climate models to a terrestrial carbon cycle feedback, and the uncertain sign of that feedback, makes resolving the role of the terrestrial biosphere on the carbon balance a high priority.

In FY 2010, the activity will continue ongoing research and initiate new research to understand important potential effects of climate change, and increasing atmospheric carbon dioxide concentration, on terrestrial ecosystems and the terrestrial carbon cycle. Continuing research will support AmeriFlux, the network of $CO_2$ flux, for directly estimating net ecosystem production and carbon sequestration by terrestrial ecosystems. Continuing research on data analysis and model development will support the activity goals. The new activities will include, as recommended by a BERAC subcommittee and a subsequent workshop[a], development of the next-generation of ecosystem-climate change experiment, with a focus on ecosystems that: are of significant importance at the regional or global scales; are expected to be sensitive to climate change; and have been poorly studied to date. The increased funding will support the development of the experimental framework and the target ecosystem will be identified in 2009–2010 based on analysis of the most recent climate model projections. In FY 2010, based on input from the scientific community, an experimental site will be located, the ecological characterization of the

[a] See the report of the BERAC Subcommittee "Reviewing the FACE and OTC Elevated $CO_2$ Projects in DOE and Ecosystem Experiments: Understanding Climate Change Impacts on Ecosystems and Feedbacks to the Physical Climate."

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|

site will begin, and the engineering methods for environmental manipulations will be prototyped in a field setting.

| | | | |
|---|---|---|---|
| ▪ **Terrestrial Carbon Sequestration Research** | **4,896** | **5,233** | **4,747** |

Terrestrial Carbon Sequestration research supports efforts to identify, understand, and predict the fundamental physical, chemical, biological, and genetic mechanisms controlling carbon sequestration in terrestrial ecosystems including soils. These challenges are addressed by identifying the physical, biological, and chemical processes controlling soil carbon input, distribution, and longevity; developing models of these systems to predict future scenarios and to inform larger-scale coupled earth systems models; and seeking ways to exploit these processes to enhance carbon sequestration in terrestrial ecosystems. Current research focuses on switchgrass (*Panicum virgatum*) ecosystems associated with DOE's cellulosic ethanol research. Preliminary results indicate that switchgrass' extensive rooting system could be managed for enhanced soil carbon sequestration.

In FY 2010, ongoing research will seek to determine if "double dividends" can be achieved from switchgrass systems that provide above-ground cellulose for ethanol production and simultaneously enhance belowground carbon sequestration. The overall goal is to understand and quantify physical, chemical, and biological controls over soil carbon sequestration using switchgrass as the test bed. The research will be carried out through field experiments with switchgrass, which will produce results on below-ground carbon transformations that involve plant roots, the rhizosphere, and soil microbial communities. The role of microaggregates and other soil properties in stabilizing and protecting carbon complexed with soil minerals will also be investigated. Data from the field experiments will be utilized for mechanistic and prognostic modeling of soil carbon sequestration. A focused experiment on climate mitigation initiated in 2009 to study the role of subsurface process in sequestration will achieve its goals and be completed in 2010.

| | | | |
|---|---|---|---|
| ▪ **Subsurface Biogeochemical Research** | **46,915** | **48,485** | **49,898** |

The Subsurface Biogeochemical Research activity addresses fundamental science questions at the intersection of biology, geochemistry, and physics to describe complex processes in key subsurface environments. The activity builds on BER advances in genome science and promotes cross-disciplinary research to link interdependent relationships between microbial metabolism and gene expression, mineral transformation, and solution composition in the environment. The current focus of the activity is to predict the impact of biogeochemical processes on the fate and transport in the subsurface. This activity supports field research sites at Oak Ridge, Tennessee; Hanford, Washington; and Rifle, Colorado (a uranium mill tailings site). These field sites provide researchers opportunities to obtain samples of environmental media from DOE sites for further evaluation in the laboratory and to test laboratory-derived hypotheses regarding subsurface biogeochemical transport at the field scale. These field sites also are important for testing and evaluating computer models that describe contaminant mobility in the environment. Strong ties have been developed between the Environmental Molecular Sciences Laboratory and subsurface biogeochemical researchers. This activity includes support for SciDAC research on advanced models to predict the mobility of subsurface contaminants.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| | (dollars in thousands) | | |

This fundamental research provides the scientific foundation for the solution of key environmental challenges within DOE and other agencies. These challenges include nuclear waste cleanup, carbon sequestration, and monitoring of contaminants in groundwater around existing and future radionuclide waste disposal and storage sites. These efforts will also assist the Department's research on using deep geological formations to store carbon dioxide taken from the atmosphere.

In FY 2010, integrated multi-scale, multi-disciplinary research will continue, emphasizing the integrated field research challenge sites. The increased research effort addresses processes that control the mobility of radionuclides in the environment. This research will help address DOE strategic initiatives for clean up of legacy nuclear wastes and nuclear energy applications. Increased funding will support fundamental research on reactive transport of transuranic contaminants in the subsurface.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **Climate and Earth System Modeling** | **35,141** | **72,029** | **69,775** |
| ▪ **Regional and Global Climate Modeling** | **21,795** | **36,801** | **27,856** |

Regional and Global Climate Modeling focuses on the research application of regional and global climate models to develop climate change projections on temporal scales of decades to centuries and spatial scales from regions to the globe. The activity supports research in the following core areas: climate model diagnosis and intercomparison through the use of appropriate metrics, detection and attribution of climate change, analysis of multi-model climate change simulations and projections, and understanding of natural and forced variability of the climate system.

Regional and Global Climate Modeling supports the basic research needed to achieve the goals of the core areas and support for national and international climate modeling research and assessments. Currently gaps exist in our knowledge of how modes of climate variability (e.g., the El Nino Southern Oscillation, Pacific Decadal Oscillation, and Northern Annular Mode) changes as atmospheric greenhouse gas concentrations continue to increase.

In FY 2010, analyses will be conducted on a suite of global climate modeling experiments that are currently being planned under the auspices of the Working Group of Coupled Modeling (WGCM) of the World Climate Research Program. These simulations will be conducted by approximately 20 modeling groups world-wide, one of which will be supported by BER. It is anticipated this activity will be coordinated with other federal agencies, e.g., NASA, NOAA, and NSF. The analysis of these climate change projections will comprise the Climate Model Intercomparison Project (CMEP5). Research will also continue to support and coordinate model-data intercomparisons, the development and improvement of metrics and diagnostic tools for evaluating model performance, and the maintenance of test beds for evaluating model parameterizations. The effort will move beyond the traditional testing of atmospheric models to include testing and evaluation of high resolution ocean models, e.g., eddy permitting and eddy-resolving simulations. A peer-reviewed, multiyear-funded activity on regional modeling was begun in FY 2009 and will be completed in FY 2010. Additionally, a Congressionally-directed, collaborative activity with NNSA on scaling models from global to regional was begun in FY 2009 and will be completed in FY 2010.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| ▪ **Earth System Modeling** | **8,536** | **25,596** | **30,596** |

Earth System Modeling develops the components and the coupling mechanisms needed to develop the coupled atmosphere-ocean-land-sea ice models for simulating climate variability and change over decadal to centennial time scales, and thus provides the research results that underpin the Regional and Global Climate Modeling research activities. Research focuses on the incorporation of improved physical presentations in the specific modules of the coupled model. The focus is on incorporation and testing of various aerosol schemes, convection schemes, ice sheets, and land surface schemes in the coupled models, and evaluation using innovative metrics that span a variety of climate time scales. Research to increase model resolution and computational performance is also conducted. The latter effort is closely coordinated with BER's SciDAC Climate Change Research activities and enhances BER's partnerships with the Advanced Scientific Computing Research program. This partnership specifically addresses scaling and other computational issues, so that needed high throughput is achieved. The Earth System Modeling research has been informed by workshops attended by national and international modeling experts.

During the past decade, considerable advances have been made in the understanding, detection, and attribution of past climate change and in projecting future changes in climate using state-of-the-art climate models. However, uncertainties due to climate forcings and feedbacks have not yet been resolved; for example, current coupled atmosphere-ocean-land-sea ice models still have systematic precipitation biases. Improvements are needed before models can simulate regional climate variability and change with greater fidelity.

In FY 2010, BER will focus on improvement and evaluation of earth system models incorporating advanced representations of cloud-aerosol and carbon-cycle-climate interactions; global cloud resolving modeling; incorporation of land-ice in the coupled climate model; and predictability on decadal time scales using ocean initialization. For example, the spread in climate change projections resulting from the use of different climate models has been identified as largely due to the different way cloud feedbacks are represented in different general circulation models, and it has been noted that atmospheric aerosols are one of the largest sources of uncertainty in quantifying radiative forcing. To advance the field, systematic development and thorough testing of various cloud and aerosol representations developed by improved process understanding is needed. The climate modeling program will continue to investigate physical mechanisms that have the potential to lead to abrupt climate change. Research will continue to improve the understanding of thresholds and nonlinearities in the climate system with a focus on mechanisms of abrupt climate change, incorporating these mechanisms into Earth System Models, and testing the models vis-à-vis records of past abrupt climate change.

In FY 2010, a focused activity will be undertaken to evaluate how earth system models simulate major modes of low frequency climate variability and how these are likely to change under enhanced greenhouse forcing. A new activity in FY 2010 for model visualization will develop new onsite and remote-access tools for model development and evaluation, real-time planning for field campaigns, and for expediting model intercomparisons. This visualization activity will provide access to several data sources, including the ARM facility data, needed to meet the goals of the activity. The visualization activity will enable users to render the data in a form that displays the evolution of the climate state variable and will provide powerful tools for testing hypotheses.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |

Congressionally-directed, collaborative activities with NNSA on climate modeling and linking ground and space observations were begun in FY 2009 and will be completed in FY 2010.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **Integrated Assessment** | **4,810** | **9,632** | **11,323** |

Integrated Assessment research provides scientific insights into options for mitigation and adaptation to climate change through multi-scale models of the entire climate system, including human processes responsible for greenhouse gas emissions, land use, and combined impacts on and feedbacks from changing human and natural systems, including the energy system. Importantly, Integrated Assessment research develops advanced quantitative tools for exploring the implications of science and technology decisions and innovations on our energy, environmental, and economic futures.

Research focuses on improving the fundamental knowledge and methodologies for analysis of climate change impacts and adaptations within integrated assessment frameworks; innovative general approaches to modeling impacts and adaptation; development of different measures of impacts; and developing approaches to addressing probabilities and uncertainties. Understanding the role of present and possible future energy technologies remains a central focus of the research, leading to improved understanding of potential emissions trajectories and the environmental costs and benefits of stabilization options.

In FY 2010, BER will enhance research to enable new efforts and progress on several key research challenges identified in the recent Integrated Assessment Research Workshop held in November of 2008. And importantly, it responds to the challenge of "Science for Science Policy."[a] In particular, Integrated Assessment provides the scientifically rigorous, quantitative basis from which policy makers and researchers may assess the impacts of the Nation's scientific and engineering enterprise, improve their understanding of its dynamics, and assess likely outcomes for decision-making on our climate, energy, economic futures. The enhanced research also responds to expressed congressional interest in developing improved science-based decision support tools on the human dimensions of climate change. Specifically, the increased funding would: pursue new and improved methodologies for representing the role of science, innovation, and potential transformational technological improvements within current modeling and analysis frameworks; support the incorporation of explicit representation of impacts adaptations within integrated assessment models with an initial emphasis on energy and infrastructure vulnerabilities and natural systems that significantly influence the overall carbon cycle; initiate development of regional modeling methods and capabilities to respond to critical needs for regional information; improve representations of energy-water-land interactions and interdependencies at relevant spatial and temporal scales; and support expansion beyond economics to reveal risk and uncertainty in perspectives of integrated assessment modeling. A Congressionally-directed, collaborative activity with NNSA to develop decision tools was initiated in FY 2009 and will be completed in FY 2010.

[a] http://www.ostp.gov/galleries/NSTC%20Reports/39924_PDF%20Proof.pdf

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| **Climate and Environmental Facilities and Infrastructure** | **88,944** | **94,450** | **99,479** |
| ▪ **Atmospheric Radiation Measurement Climate Research Facility** | **37,644** | **40,353** | **41,809** |

The Atmospheric Radiation Measurement Climate Research Facility (ACRF) is a multi-platform national scientific user facility, with stationary and mobile platforms and instruments at fixed and varying locations around the globe. ACRF provides continuous field measurements of climate data to promote the advancement of atmospheric process understanding and climate models through precise observations of atmospheric phenomena. The stationary sites provide scientific testbeds in three different climate regions (mid-latitude, polar, and tropical); the operating paradigm of continuous measurement of atmospheric and surface properties at long-term sites is well suited to climate studies. The two mobile facilities provide a capability to address high priority scientific questions in other regions. The ACRF aerial capability provides in situ cloud and radiation measurements that complement the ground-based measurements.

ACRF provides unparalleled continuous, long-term observations needed to develop and test understanding of the central role of clouds in the Earth's climate and to determine the effects of aerosol emissions on the atmospheric radiation balance. The role of clouds and the effects of aerosols are the two largest uncertainties in climate change research.

In FY 2010, ACRF will continue its long-term observations from the fixed sites and will conduct four field experiments to study various cloud types—cirrus, marine, and mixed-phase (ice and water)—to improve computer models that simulate climate change. In 2010, new aerosol measurements from the Darwin site will be available to users; these data will support research on the impacts of biomass burning in the region. A campaign at the Southern Great Plains site will address outstanding questions regarding mid-latitude cirrus properties and processes. The first mobile facility will be deployed to study low marine clouds and aerosols in the Azores. The second mobile facility will study liquid and mixed-phase clouds in Colorado. These measurements support research efforts designed to address the largest uncertainties in the climate models. The increased funding will support a field experiment at the North Slope of Alaska site that will be the first to capture a full atmospheric profile of in situ cloud microphysics, aerosols, and radiative measurements during the arctic transition season.

Additional funds will also cover increased contractor defined-benefit pension liabilities costs at Pacific Northwest National Laboratory.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |

| | (estimated) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Achieved Operating Hours | 8,320 | N/A | N/A |
| Planned Operating Hours | 7,905 | 7,884 | 7,884 |
| Optimal hours | 7,905 | 7,884 | 7,884 |
| Percent of Optimal Hours | 105% | 100% | 100% |
| Unscheduled Downtime | N/A | N/A | N/A |
| Number of Users[a] | 1,092 | 1,000 | 1,000 |

- **Environmental Molecular Sciences Laboratory** **42,568** **48,448** **52,021**

The William R. Wiley Environmental Molecular Sciences Laboratory (EMSL), a scientific user facility located at the Pacific Northwest National Laboratory, provides integrated experimental and computational resources for discovery and technological innovation in the environmental molecular sciences for DOE and the Nation. With more than fifty leading-edge instruments and a supercomputer, EMSL enables users to undertake molecular-scale experimental and theoretical research on aerosol chemistry, biological systems, biogeochemistry, and interfacial and surface science.

EMSL encourages the use of multiple systems to provide fundamental understanding of the physical, chemical, and biological processes that underlie DOE's energy and environmental missions, including alternative energy sources, improved catalysts and materials for industrial applications, insights into the factors influencing climate change and carbon sequestration processes, and an understanding of subsurface biogeochemistry at contaminated sites. For example, EMSL's nuclear magnetic resonance (NMR) spectrometers; high resolution mass spectrometers; ultra-high vacuum scanning, tunneling, cryogenic and atomic force microscopy capabilities; and the 160 TeraFlop supercomputer are all used to study microbial and plant species important for bioenergy and other energy sources. The EMSL capability for proteomics is unique and essential for advances in the field of systems biology.

In FY 2010, EMSL operations funding is held near level, maintaining user facility operations and service to users. The FY 2009 budget request proposed a multiyear instrument refreshment activity and that effort will continue in FY 2010. Capital equipment support for EMSL enables instrument upgrades and modifications as well as the development and procurement of unique state-of-the-art capabilities needed by external users and EMSL staff to conduct innovative and leading-edge science. The new instrument requirements were derived from user workshops that brought together hundreds of scientists to discuss new capabilities needed for addressing the EMSL science themes. Additional programmatic general plant project funding is provided to complete construction of an addition to EMSL for radiochemistry that was initiated in FY 2009. This will provide the scientific community with advanced experimental resources for interfacial molecular

[a] ARM users are both onsite and remote. A user is an individual who accesses ARM databases or uses equipment at an ARM site. Individuals are only counted once per year at an individual site but may be counted at different ARM sites if they are a user at more than one site.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |

science studies of radionuclides in environmental applications.

In FY 2010, funding will be provided for the following Major Items of Equipment: an Advanced Oxygen Plasma Assisted Molecular Beam Epitaxy (OPA-MBE) with a Total Estimated Cost of $3,200,000; a Secondary Ion Mass Spectrometer (SIMS) with a Total Estimated Cost of $4,500,000; and a Next Generation, High Magnetic Field Mass Spectrometer (HFMS) with a Total Estimated Cost of $3,000,000. These instruments will enable synthesis and characterization of oxide films and surfaces; provide extremely high resolution images and quantitative data of organic and inorganic samples; and enable world-leading proteomics, metabolomics and lipidomics with application to bioenergy, as well as provide insights relevant to climate science, fossil fuel processing, and catalysis.

| | (estimated) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Achieved Operating Hours | 4,340 | N/A | N/A |
| Planned Operating Hours | 4,365 | 4,365 | 4,365 |
| Optimal hours | 4,365 | 4,365 | 4,365 |
| Percent of Optimal Hours | 99.4% | 100% | 100% |
| Unscheduled Downtime | 25 | N/A | N/A |
| Number of Users[a] | 643 | 750 | 750 |

- **Data Management and Education** **4,200** **4,199** **4,199**

The role of climate data management is to facilitate full and open access to quality-assured carbon cycle data for climate change research. Data holdings include records of the concentrations of atmospheric $CO_2$ and other greenhouse gases; the role of the terrestrial biosphere and the oceans in biogeochemical cycles of greenhouse gases; emissions of $CO_2$ to the atmosphere; long-term climate trends; the effects of elevated $CO_2$ on vegetation; and the vulnerability of coastal areas to rising sea level. Data management support for major projects, such as the AmeriFlux network, measurements of $CO_2$ taken aboard ocean research vessels, and DOE-supported Free-Air $CO_2$ Enrichment (FACE) experiments, are also included.

The Global Change Education Program (GCEP) supports undergraduate and graduate students conducting research on climate change using mentors from the DOE national laboratories and other institutions. GCEP supports both undergraduate and graduate studies through the DOE Summer Undergraduate Research Experience (SURE) and the DOE Graduate Research Environmental Fellowships (GREF). Their research is conducted under a mentor of their choice at either a university or a DOE laboratory. Funding for GREF and SURE only supports the students, not the mentor under whom they each choose to work. The SURE continues to be a magnet for highly qualified undergraduates, most of whom attend graduate school to study in fields directly related to their projects under SURE. Similarly, students in the GREF program have received graduate degrees and many have stayed in the field and initiated their own research.

In FY 2010, the data management activity will continue to support data users with tools for

[a] EMSL users are both onsite and remote. Individual users are counted once per year.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| identifying and accessing those data needed to address important climate change research questions. The activity will also implement information technology advances to meet evolving data sharing needs of researchers. These include user interfaces, visualization capabilities, and customized data extractions from large, often complex, data files. BER's Global Change Education Program will continue to support approximately 45 students to conduct research that is relevant to DOE's climate change research. | | | |
| ▪ **General Purpose Equipment (GPE)** | **402** | **750** | **750** |
| GPE funding provides general purpose equipment for Pacific Northwest National Laboratory (PNNL) and Oak Ridge Institute for Science and Education (ORISE), such as information system computers and networks and instrumentation that supports multi-purpose research. | | | |
| ▪ **General Plant Projects (GPP)** | **4,130** | **700** | **700** |
| GPP funding supports minor construction, capital alterations, and additions, such as replacing utility systems in 30 to 40 year old buildings. Funding of this type is essential for maintaining the productivity and usefulness of Department-owned facilities and meeting the requirements for safe and reliable facilities operation. This activity includes stewardship funding for ORISE. The total estimated cost of each GPP project will not exceed $10,000,000. | | | |
| **SBIR/STTR** | **—** | **7,299** | **7,442** |
| In FY 2008, $5,118,000 and $483,000 were transferred to the SBIR and STTR programs, respectively. FY 2009 and FY 2010 amounts shown are the estimated requirements for continuation of the congressionally mandated SBIR and STTR programs. | | | |
| **Total, Climate and Environmental Sciences** | **227,102** | **278,725** | **285,706** |

## Explanation of Funding Changes

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| **Atmospheric System Research** | |
| The increase will support additional development and testing of atmospheric model formulations for cloud and aerosol processes for the next generation Earth System Model. | +1,136 |
| **Environmental System Science** | |
| ▪ **Terrestrial Ecosystem Science** | |
| The increased funding will initiate the next-generation of large-scale, long-term manipulative field experiments, with a focus on an ecosystem that has to date been poorly studied; is expected to be sensitive to climate change; and is of significant importance at the regional or global scales. | +2,000 |

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| ▪ **Terrestrial Carbon Sequestration Research** | |
| Funding is decreased as a focused experiment on climate mitigation initiated in 2009 to study the role of subsurface process in sequestration will achieve its goals and be completed in 2010. | -486 |
| ▪ **Subsurface Biogeochemical Research** | |
| Increased funding will support fundamental research on reactive transport of transuranic contaminants in the subsurface, increasing the likelihood for success in DOE strategic initiatives for clean up of legacy nuclear wastes and nuclear energy applications. | +1,413 |
| **Total, Environmental System Science** | **+2,927** |
| **Climate and Earth System Modeling** | |
| ▪ **Regional and Global Climate Modeling** | |
| Funding is decreased as multiyear activities are completed in FY 2010. A peer-reviewed, multiyear-funded activity on regional modeling was begun in FY 2009 and will be completed in FY 2010. Additionally, a focused, multiyear-funded, collaborative activity with NNSA on scaling models from global to regional was begun in FY 2009 and will be completed in FY 2010. | -8,945 |
| ▪ **Earth System Modeling** | |
| The increase will develop a visualization activity for model development and evaluation, real-time field campaign planning, and model intercomparisons. The increase will also support a focused activity to evaluate how earth system models simulate major modes of low-frequency climate variability (El Nino Southern Oscillation, Pacific Decadal Oscillation, and Northern Annular Mode) and how these are likely to change under greenhouse forcing. Funding for multiyear, focused, collaborative activities with NNSA on climate modeling and linking ground and space observations are completed in FY2010. | +5,000 |
| ▪ **Integrated Assessment** | |
| Funding is increased to enable new efforts and progress on key research challenges including: 1) the incorporation of explicit representation of impacts and adaptations within integrated assessment models; 2) the development of regional modeling methods and capabilities; 3) improved representations of energy-water-land interactions and interdependencies at relevant spatial and temporal scales; and 4) expansion beyond economics to reveal risk and uncertainty for perspectives of integrated assessment modeling. | +1,691 |
| **Total, Climate and Earth System Modeling** | **-2,254** |

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| **Climate and Environmental Facilities and Infrastructure** | |
| ▪ **ARM Climate Research Facility** | |
| The increase will support a field experiment at the North Slope of Alaska site that will be the first to capture a full atmospheric profile of in situ cloud microphysics, aerosols and radiative measurements during the arctic transition season. | +1,456 |
| ▪ **EMSL Operations and Infrastructure** | |
| The increase in EMSL capital equipment funding is provided to continue refresh of capital equipment for EMSL that was initiated in FY 2009. Additional programmatic GPP funding is provided to complete construction of an addition to EMSL for radiochemistry that was initiated in FY 2009. | +3,573 |
| **Total, Climate and Environmental Facilities and Infrastructure** | **+5,029** |
| **SBIR/STTR** | |
| SBIR/STTR is increased as research support is enhanced. | +143 |
| **Total Funding Change, Climate and Environmental Sciences** | **+6,981** |

## Supporting Information

## Operating Expenses, Capital Equipment and Construction Summary

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Operating Expenses | 507,554 | 554,101 | 560,666 |
| Capital Equipment | 19,379 | 28,777 | 24,164 |
| General Plant Projects (GPP) | 4,130 | 2,700 | 3,200 |
| Other | — | 15,962 | 16,152 |
| Total BER | 531,063 | 601,540 | 604,182 |

## Funding Summary

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Research | | | |
| National Laboratories | 229,414 | 265,000 | 265,991 |
| University Research | 126,439 | 128,888 | 120,921 |
| Other Research[a] | 5,955 | 19,139 | 5,838 |
| Total Research | 361,808 | 413,027 | 392,750 |
| | | | |
| Scientific User Facilities Operations and Research | 160,223 | 169,101 | 178,130 |
| Major Items of Equipment | 4,500 | — | 10,700 |
| Facility related GPP | — | 2,000 | 2,500 |
| Other[b] | 4,532 | 17,412 | 20,102 |
| Total BER | 531,063 | 601,540 | 604,182 |

## Scientific User Facilities Operations and Research

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Biological Systems Science | | | |
| Structural Biology Infrastructure | 15,446 | 15,300 | 15,300 |
| Joint Genomics Institute | 64,565 | 65,000 | 69,000 |
| Total, Biological Systems Science | 80,011 | 80,300 | 84,300 |

[a] Includes funding for other Federal Agencies and Industrial Firms.
[b] Includes General Purpose Equipment, GPP, SBIR and STTR.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Climate and Environmental Sciences | | | |
| Atmospheric Radiation Measurement Climate Research Facility | 37,644 | 40,353 | 41,809 |
| Environmental Molecular Sciences Laboratory | 42,568 | 48,448 | 52,021 |
| Total, Climate and Environmental Science | 80,212 | 88,801 | 93,830 |
| Total Science User Facilities Operations and Research | 160,223 | 169,101 | 178,130 |

## Facilities Users and Hours

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| Joint Genome Institute | | | |
| Achieved Operating Hours | 7,704 | N/A | N/A |
| Planned Operating Hours | 8,400 | 8,400 | 8,400 |
| Optimal hours | 8,400 | 8,400 | 8,400 |
| Percent of Optimal Hours | 92% | 100% | 100% |
| Unscheduled Downtime | 696 | N/A | N/A |
| Number of Users[a] | 679 | 780 | 940 |
| Atmospheric Radiation Measurement (ARM)Climate Research Facility (ACRF) | | | |
| Achieved Operating Hours | 8,320 | N/A | N/A |
| Planned Operating Hours | 7,905 | 7,884 | 7,884 |
| Optimal hours | 7,905 | 7,884 | 7,884 |
| Percent of Optimal Hours | 105% | 100% | 100% |
| Unscheduled Downtime | N/A | N/A | N/A |
| Number of Users[b] | 1,092 | 1,000 | 1,000 |

[a] All JGI users are remote. Primary users are individuals associated with approved projects being conducted at the JGI in a reporting period. Each user is counted once per year regardless of how many proposals their name may be associated with. Additionally, different users reflect vastly differing levels of JGI resources.

[b] ARM users are both onsite and remote. A user is an individual who accesses ARM databases or uses equipment at an ARM site. Individuals are only counted once per reporting period at an individual site but may be counted at different ARM sites if they are a user at more than one site.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| Environmental Molecular Sciences Laboratory | | | |
| Achieved Operating Hours | 4,340 | N/A | N/A |
| Planned Operating Hours | 4,365 | 4,365 | 4,365 |
| Optimal hours | 4,365 | 4,365 | 4,365 |
| Percent of Optimal Hours | 99.4% | 100% | 100% |
| Unscheduled Downtime | 25 | N/A | N/A |
| Number of Users[a] | 643 | 750 | 750 |
| | | | |
| Total Facilities | | | |
| Achieved Operating Hours | 20,365 | N/A | N/A |
| Planned Operating Hours | 20,670 | 20,649 | 20,649 |
| Optimal hours | 20,670 | 20,649 | 20,649 |
| Percent of Optimal Hours | 98.5% | 100% | 100% |
| Unscheduled Downtime | 721 | N/A | N/A |
| Number of Users | 1,670 | 1,770 | 1,775 |

Structural Biology Infrastructure activities are at Basic Energy Sciences program facilities and the user statistics are included in the BES user statistics.

## Major Items of Equipment

(dollars in thousands)

| | Prior Years | FY 2008 | FY 2009 | FY 2009 Additional Approp. | FY 2010 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| Atmospheric Radiation Measurement (ARM) Climate Research Facility (ACRF) | | | | | | | |
| Dual-Frequency Scanning Cloud Radar for Southern Great Plains ARM Site | | | | | | | |
| Total Estimated Costs (TEC)/Total Project Costs (TPC) | — | — | — | 3,000 | — | — | 3,000 |
| Dual-Frequency Scanning Cloud Radar for North Slope of Alaska ARM Site | | | | | | | |
| TEC/TPC | — | — | — | 3,000 | — | — | 3,000 |
| Dual-Frequency Scanning Cloud Radar for Tropical Western Pacific (Manus) ARM Site | | | | | | | |
| TEC/TPC | — | — | — | 3,000 | — | — | 3,000 |

[a] EMSL users are both onsite and remote. Individual users are counted once per year.

(dollars in thousands)

| | Prior Years | FY 2008 | FY 2009 | FY 2009 Additional Approp. | FY 2010 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| Dual-Frequency Scanning Cloud Radar for ARM Mobile Facility #1 | | | | | | | |
| TEC/TPC | — | — | — | 3,000 | — | — | 3,000 |
| Dual-Frequency Scanning Cloud Radar for ARM Mobile Facility #2 | | | | | | | |
| TEC/TPC | — | — | — | 3,000 | — | — | 3,000 |
| Dual-Frequency Scanning Cloud Radar for Tropical Western Pacific (Darwin) ARM Site | | | | | | | |
| TEC/TPC | — | — | — | 3,000 | — | — | 3,000 |
| Raman Lidar | | | | | | | |
| TEC/TPC | — | — | — | 2,100 | — | — | 2,100 |
| Total ACRF TEC/TPC | — | — | — | 20,100 | — | — | |
| Environmental Molecular Sciences Laboratory (EMSL) | | | | | | | |
| Field Emission-Transmission Electron Microscope (FE-TEM) | | | | | | | |
| TEC/TPC | — | 4,500 | — | — | — | — | 4,500 |
| Standard Transmission Electron Microscope (TEM) | | | | | | | |
| TEC/TPC | — | — | — | 2,865 | — | — | 2,865 |
| X-ray Phtotelectron Spectrometer (XPS) | | | | | | | |
| TEC/TPC | — | — | — | 2,060 | — | — | 2,060 |
| 3-D Atom Probe | | | | | | | |
| TEC/TPC | — | — | — | 2,335 | — | — | 2,335 |
| Electron Microprobe | | | | | | | |
| TEC/TPC | — | — | — | 2,335 | — | — | 2,335 |
| 700 Mega-Hertz Wide Bore Nuclear Magnetic Resonance (NMR) Spectrometer | | | | | | | |
| TEC/TPC | — | — | — | 2,600 | — | — | 2,600 |
| 15 Tesla Fourier Transform-Ion Cyclotron Resonance (FT-ICR) Mass Spectrometer (MS) | | | | | | | |
| TEC/TPC | — | — | — | 2,850 | — | — | 2,850 |

(dollars in thousands)

| | Prior Years | FY 2008 | FY 2009 | FY 2009 Additional Approp. | FY 2010 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| Ultra-High Vacuum (UHV) Scanning Tunneling Microscope/Atomic Force Microscope (STM/AFM) | | | | | | | |
| TEC/TPC | — | — | — | 2,200 | — | — | 2,200 |
| 850 MegaHertz Wide Bore Nuclear Magnetic Resonance (NMR) Spectrometer | | | | | | | |
| TEC/TPC | — | — | — | 4,425 | — | — | 4,425 |
| 3-D Microscope System (e.g., Helium Ion Microscope) | | | | | | | |
| TEC/TPC | — | — | — | 2,025 | — | — | 2,025 |
| Integrated Optical Spectroscopy System | | | | | | | |
| TEC/TPC | — | — | — | 2,075 | — | — | 2,075 |
| Advanced Mass Spectrometry System | | | | | | | |
| TEC/TPC | — | — | — | 2,680 | — | — | 2,680 |
| Advanced Oxygen Plasma Assisted Molecular Beam Epitaxy (OPA-MBE) system | | | | | | | |
| TEC/TPC | — | — | — | — | 3,200 | — | 3,200 |
| Secondary Ion Mass Spectrometer (SIMS) | | | | | | | |
| TEC/TPC | — | — | — | — | 4,500 | — | 4,500 |
| Next Generation, High Magnetic Field Mass Spectrometer (HFMS) | | | | | | | |
| TEC/TPC | — | — | — | — | 3,000 | 14,500 | 17,500 |
| Total EMSL TEC/TPC | | 4,500 | — | 28,450 | 10,700 | | |
| Total BER TEC/TPC | | 4,500 | — | 48,550 | 10,700 | | |

## Atmospheric Radiation Measurement (ARM) Climate Research Facility (ACRF)

*Dual-frequency scanning cloud radar for the Southern Great Plains ARM Site.* This instrument will provide the capability to measure cloud properties in a volume and will provide three-dimensional cloud properties at the Southern Great Plains ARM Site. These data are essential for developing high-resolution climate models.

*Dual-frequency scanning cloud radar for the North Slope of Alaska ARM Site.* This instrument will provide the capability to measure cloud properties in a volume and will provide three-dimensional cloud properties at the North Slope of Alaska ARM Site. These data are essential for developing high-resolution climate models.

*Dual-frequency scanning cloud radar for the Tropical Western Pacific (Manus) ARM Site.* This instrument will provide the capability to measure cloud properties in a volume and will provide three-dimensional cloud properties at the Tropical Western Pacific (Manus) ARM Site. These data are essential for developing high-resolution climate models.

*Dual-frequency scanning cloud radar for the ARM Mobile Facility #1.* This instrument will provide the capability to measure cloud properties in a volume and will provide three-dimensional cloud properties for the ARM Mobile Facility #1. These data are essential for developing high-resolution climate models.

*Dual-frequency scanning cloud radar for the ARM Mobile Facility #2.* This instrument will provide the capability to measure cloud properties in a volume and will provide three-dimensional cloud properties for the ARM Mobile Facility #2. These data are essential for developing high-resolution climate models.

*Dual-frequency scanning cloud radar for the Tropical Western Pacific (Darwin) ARM Site.* This instrument will provide the capability to measure cloud properties in a volume and will provide three-dimensional cloud properties at Tropical Western Pacific (Darwin) ARM Site. These data are essential for developing high-resolution climate models.

*Raman Lidar.* This instrument will provide the capability to measure vertical profiles of water vapor, aerosols, and cloud properties. These data are essential for developing high-resolution climate models.

**Environmental Molecular Sciences Laboratory**

*Field Emission-Transmission Electron Microscope (FE-TEM)* will allow imaging of reactions at the atomic scale under high temperature and pressure conditions. This understanding will be key to assess the reactivity of novel materials for use in hydrogen fuel cells and for examining the conversion of organic matter into alternative fuels.

*Standard Transmission Electron Microscope (TEM)* to replace EMSL's workhorse TEM. Enables nano-meter structural and chemical characterization of complex synthesized and natural materials relevant to catalysis, fuels cells, energy storage and sensing.

*X-ray Photoelectron Spectrometer (XPS)* will enable three dimensional chemical maps of the outer 50 nanometers of natural materials as well as designed or degraded functionalized materials. Relevant to mineral/contaminant interactions, aging and degradation of solar cells and solid state lighting and catalytic surfaces.

*Atom Probe* for three dimensional atomic scale imaging of complex materials including solid-solid "buried" interfaces. To be used for material surface studies relevant to subsurface remediation, photovoltaics and catalysis.

*Electron Microprobe* provides elemental composition and structural imaging of materials/minerals. Relevant to radiological applications such as waste storage and processing.

*700 Megahertz Wide Bore Nuclear Magnetic Resonance (NMR) Spectrometer* system to perform solid-state and liquids NMR measurements of radiological-containing and radiologically-exposed materials.

*15 Tesla Fourier Transform Ion Cyclotron Resonance (FT-ICR) Mass Spectrometer* to replace EMSL's original 11.5 Tesla system. Application to intact proteins and protein modification studies to fundamentally advance biological science insights for microbial and plant systems.

*Ultra-High Vacuum (UHV) Scanning Tunneling Microscope/Atomic Force Microscope (STM/AFM)* will enable site-specific chemical measurements with unique abilities to control the arrival of molecules at the site. To be used for research on catalysts for fuel cell operation, contaminant destruction and energy production.

*850 MegaHertz Wide Bore Nuclear Magnetic Resonance (NMR) Spectrometer* will be optimized for solid-state investigation of materials and metallic systems and would be relevant to energy-relevant materials (including catalysts) and minerals and contaminants.

*Three Dimensional Microscope System (e.g., Helium Ion Microscope)* will provide Transmission Electron Microscope-like resolution of bulk samples and will provide new 3D information on aerosol particles, microbial/mineral interfaces, catalytic surfaces and other materials.

*Integrated Optical Spectroscopy System* combines three approaches for the study of surfaces and interfaces and will be useful in advancing alternative energy sources, processing science and geochemistry.

*Advanced Mass Spectrometry System* with liquid chromatography capability for the identification and quantification of peptides and proteins to aid in studies of microbial communities and plant systems.

*Advanced Oxygen Plasma Assisted Molecular Beam Epitaxy (OPA-MBE)* system is designed for the growth of a wide variety of oxide materials and will be funded at $3,200,000 total estimated cost (TEC) in FY 2010 and delivered in FY 2011. This instrument will enable synthesis and characterization of oxide films and surfaces important for catalysis, electronic and spintronic materials, and geochemistry.

*Secondary Ion Mass Spectrometer (SIMS)* will be used for high spatial resolution as well as trace element and isotopic analysis of ultra-fine features and will be funded at $4,500,000 TEC in FY 2010 and delivered in FY 2011. This instrument will provide extremely high resolution of organic and inorganic samples applicable to geochemistry, aerosol particles and materials.

*Next Generation, High Magnetic Field Mass Spectrometer (HFMS)* system will be a world-leading system to measure and characterize complex mixtures of intact proteins and other biomolecules, aerosol particles, petroleum, and constituents from other types of fluids. Initially funded at $3,000,000 in FY 2010 with delivery in FY 2014, the TEC will be $17,500,000. Will enable world-leading proteomics, metabolomics and lipidomics with application to bioenergy, as well as provide insights relevant to climate science, fossil fuel processing, and catalysis.

## Scientific Employment

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| | | (estimated) | |
| # University Grants | 447 | 480 | 475 |
| Average Size per year | $320,000 | $320,000 | $320,000 |
| # Laboratory Projects | 355 | 375 | 370 |
| # Permanent Ph.D.s[a] | 1,320 | 1,480 | 1,460 |
| # Postdoctoral Associates[b] | 304 | 340 | 335 |
| # Graduate Students[c] | 429 | 485 | 480 |
| # Ph.D.s awarded[c] | 105 | 105 | 110 |

## Budget Structure Funding Crosswalk

## Biological and Environmental Research Comparability Matrix from FY 2009 to FY 2010 Budget Structure—FY 2008 Funding

(dollars in thousands)

| | FY 2009 Budget Structure | | | | | |
|---|---|---|---|---|---|---|
| | Biological Research | | | | | |
| | Life Sciences | Medical Applica-tions | Environ-mental Remedi-ation | Total, Biological Research | Climate Change Research | Total, BER |
| **FY 2010 Budget Structure** | | | | | | |
| Biological Systems Science | | | | | | |
| Genomic Science | 164,085 | — | — | 164,085 | — | 164,085 |
| Radiological Sciences | 46,674 | — | — | 46,674 | — | 46,674 |
| Ethical, Legal, and Societal Issues | 5,000 | — | — | 5,000 | — | 5,000 |
| Medical Applications | — | 8,191 | — | 8,191 | — | 8,191 |
| Biological Systems Facilities and Infrastructure | 80,011 | — | — | 80,011 | — | 80,011 |
| Total, Biological Systems Science | 295,770 | 8,191 | — | 303,961 | — | 303,961 |
| Climate and Environmental Sciences | | | | | | |
| Atmospheric System Research | — | — | — | — | 25,201 | 25,201 |
| Environmental System Science | — | — | 46,915 | 46,915 | 30,901 | 77,816 |

[a] Estimated. Information is not readily available on the total number of permanent Ph.D. scientists associated with each research project. In addition to the principal investigator for each research project funded by BER, individual projects typically have between 1 and 20 additional Ph.D.-level scientists who are funded collaborators. Information on scientific collaborators is not routinely tracked.

[b] Estimated for national laboratory projects.

[c] Estimated. Information is not available on the number of Ph.D.s awarded as a result of BER funded research at universities or national laboratories.

(dollars in thousands)

| | FY 2009 Budget Structure | | | | | |
|---|---|---|---|---|---|---|
| | Biological Research | | | | | |
| Climate and Earth System Modeling | — | — | — | — | 35,141 | 35,141 |
| Climate and Environmental Facilities and Infrastructure | — | — | 47,100 | 47,100 | 41,844 | 88,944 |
| Total Climate and Environmental Sciences | — | — | 94,015 | 94,015 | 133,087 | 227,102 |
| Total, BER | 295,770 | 8,191 | 94,015 | 397,976 | 133,087 | 531,063 |

## Life Sciences Comparability Matrix from FY 2009 to FY 2010 Budget Structure—FY 2008 Funding

(dollars in thousands)

| | FY 2009 Budget Structure | | | | | |
|---|---|---|---|---|---|---|
| | Structural Biology | Molecular & Cellular Biology | Human Genome | Health Effects | Radio-chemistry & Instru-mentation | Total, Life Sciences |
| **FY 2010 Budget Structure** | | | | | | |
| Biological Systems Science | | | | | | |
| Genomic Science | | | | | | |
| Foundational Genomics Research | — | 33,422 | — | — | — | 33,422 |
| Genomics Analysis and Validation | — | — | 10,521 | — | — | 10,521 |
| Metabolic Synthesis and Conversion | — | 41,297 | — | — | — | 41,297 |
| Computational Biosciences | — | 3,845 | — | — | — | 3,845 |
| Bioenergy Research Centers | — | 75,000 | — | — | — | 75,000 |
| Total, Genomic Science | — | 153,564 | 10,521 | — | — | 164,085 |
| Radiological Sciences | | | | | | |
| Radiochemistry and Imaging Instrumentation | — | — | — | — | 21,789 | 21,789 |
| Radiobiology | — | 17,983 | — | 6,902 | — | 24,885 |
| Total, Radiological Sciences | — | 17,983 | — | 6,902 | 21,789 | 46,674 |
| Ethical, Legal, and Societal Issues | — | — | 5,000 | — | — | 5,000 |
| Biological Systems Facilities and Infrastructure | | | | | | |
| Structural Biology Infrastructure | 15,446 | — | — | — | — | 15,446 |
| Joint Genome Institute | — | 10,000 | 54,565 | — | — | 64,565 |
| Total, Biological Systems Facilities and Infrastructure | 15,446 | 10,000 | 54,565 | — | — | 80,011 |
| Total, Biological Systems Science | 15,446 | 181,547 | 70,086 | 6,902 | 21,789 | 295,770 |

## Environmental Remediation Comparability Matrix from FY 2009 to FY 2010 Budget Structure—FY 2008 Funding

(dollars in thousands)

| | FY 2009 Budget Structure | | |
|---|---|---|---|
| | Environmental Remediation Research | Facility Operations (EMSL) | Total Environmental Remediation |
| **FY 2010 Budget Structure** | | | |
| Climate and Environmental Sciences | | | |
| Environmental System Science | | | |
| Subsurface Biogeochemical Research | 46,915 | — | 46,915 |
| Climate and Environmental Facilities and Infrastructure | | | |
| EMSL Operations | — | 42,568 | 42,568 |
| General Purpose Equipment | 4,532 | — | 4,532 |
| Total, Climate and Environmental Facilities and Infrastructure | 4,532 | 42,568 | 47,100 |
| Total Climate and Environmental Sciences | 51,447 | 42,568 | 94,015 |

## Climate Change Research Comparability Matrix from FY 2009 to FY 2010 Budget Structure—FY 2008 Funding

(dollars in thousands)

| | FY 2009 Budget Structure | | | | |
|---|---|---|---|---|---|
| | Climate Forcing | Climate Change Modeling | Climate Change Response | Climate Change Mitigation | Total, Climate Change Research |
| **FY 2010 Budget Structure** | | | | | |
| Climate and Environmental Sciences | | | | | |
| Atmospheric System Research | 25,201 | — | — | — | 25,201 |
| Environmental System Science | | | | | |
| Terrestrial Ecosystem Science | 11,849 | — | 14,156 | — | 26,005 |
| Terrestrial Carbon Sequestration Research | — | — | — | 4,896 | 4,896 |
| Total, Environmental System Science | 11,849 | — | 14,156 | 4,896 | 30,901 |
| Climate and Earth System Modeling | | | | | |
| Regional and Global Climate Modeling | — | 21,795 | — | — | 21,795 |
| Earth System Modeling | — | 8,536 | — | — | 8,536 |
| Integrated Assessment | — | — | 4,810 | — | 4,810 |
| Total, Climate and Earth System Modeling | — | 30,331 | 4,810 | — | 35,141 |

(dollars in thousands)

| | FY 2009 Budget Structure | | | | |
|---|---|---|---|---|---|
| | Climate Forcing | Climate Change Modeling | Climate Change Response | Climate Change Mitigation | Total, Climate Change Research |
| Climate and Environmental Facilities and Infrastructure | | | | | |
| ARM Operations and Infrastructure | 37,644 | — | — | — | 37,644 |
| Data Management and Education | 2,778 | — | 1,422 | — | 4,200 |
| Total, Climate and Environmental Facilities and Infrastructure | 40,422 | — | 1,422 | — | 41,844 |
| Total Climate and Environmental Sciences | 77,472 | 30,331 | 20,388 | 4,896 | 133,087 |

## Biological and Environmental Research Comparability Matrix from FY 2009 to FY 2010 Budget Structure—FY 2009 Funding

(dollars in thousands)

| | FY 2009 Budget Structure | | | | | |
|---|---|---|---|---|---|---|
| | Biological Research | | | | | |
| | Life Sciences | Medical Applica-tions | Environ-mental Remedi-ation | Total, Biological Research | Climate Change Research | Total, BER |
| **FY 2010 Budget Structure** | | | | | | |
| Biological Systems Science | | | | | | |
| Genomic Science | 169,858 | — | — | 169,858 | — | 169,858 |
| Radiological Sciences | 50,768 | — | — | 50,768 | — | 50,768 |
| Ethical, Legal, and Societal Issues | 5,000 | — | — | 5,000 | — | 5,000 |
| Medical Applications | — | 8,226 | — | 8,226 | — | 8,226 |
| Biological Systems Facilities and Infrastructure | 80,300 | — | — | 80,300 | — | 80,300 |
| SBIR/STTR | 8,663 | — | — | 8,663 | — | 8,663 |
| Total, Biological Systems Science | 314,589 | 8,226 | — | 322,815 | — | 322,815 |
| Climate and Environmental Sciences | | | | | | |
| Atmospheric System Research | — | — | — | — | 25,316 | 25,316 |
| Environmental System Science | — | — | 48,485 | 48,485 | 31,146 | 79,631 |
| Climate and Earth System Modeling | — | — | — | — | 72,029 | 72,029 |
| Climate and Environmental Facilities and Infrastructure | — | — | 49,898 | 49,898 | 44,552 | 94,450 |
| SBIR/STTR | — | — | 2,415 | 2,415 | 4,884 | 7,299 |
| Total Climate and Environmental Sciences | — | — | 100,798 | 100,798 | 177,927 | 278,725 |
| Total, BER | 314,589 | 8,226 | 100,798 | 423,613 | 177,927 | 601,540 |

## Life Sciences Comparability Matrix from FY 2009 to FY 2010 Budget Structure—FY 2009 Funding

(dollars in thousands)

| | FY 2009 Budget Structure | | | | | | |
|---|---|---|---|---|---|---|---|
| | Structural Biology | Molecular & Cellular Biology | Human Genome | Health Effects | Radio-chemistry & Instru-mentation | SBIR/ STTR | Total, Life Sciences |
| **FY 2010 Budget Structure** | | | | | | | |
| Biological Systems Science | | | | | | | |
| Genomic Science | | | | | | | |
| Foundational Genomics Research | — | 38,267 | — | — | — | — | 38,267 |
| Genomics Analysis and Validation | — | — | 10,000 | — | — | — | 10,000 |
| Metabolic Synthesis and Conversion | — | 42,127 | — | — | — | — | 42,127 |
| Computational Biosciences | — | 4,464 | — | — | — | — | 4,464 |
| Bioenergy Research Centers | — | 75,000 | — | — | — | — | 75,000 |
| Total, Genomic Science | — | 159,858 | 10,000 | — | — | — | 169,858 |
| Radiological Sciences | | | | | | | |
| Radiochemistry and Imaging Instrumentation | — | — | — | — | 22,841 | — | 22,841 |
| Radiobiology | — | 20,606 | — | 7,321 | — | — | 27,927 |
| Total, Radiological Sciences | — | 20,606 | — | 7,321 | 22,841 | — | 50,768 |
| Ethical, Legal, and Societal Issues | — | — | 5,000 | — | — | — | 5,000 |
| Biological Systems Facilities and Infrastructure | | | | | | | |
| Structural Biology Infrastructure | 15,300 | — | — | — | — | — | 15,300 |
| Joint Genome Institute | — | 10,000 | 55,000 | — | — | — | 65,000 |
| Total, Biological Systems Facilities and Infrastructure | 15,300 | 10,000 | 55,000 | — | — | — | 80,300 |
| SBIR/STTR | — | — | — | — | — | 8,663 | 8,663 |
| Total, Biological Systems Science | 15,300 | 190,464 | 70,000 | 7,321 | 22,841 | 8,663 | 314,589 |

## Environmental Remediation Comparability Matrix from FY 2009 to FY 2010 Budget Structure—FY 2009 Funding

(dollars in thousands)

| | FY 2009 Budget Structure | | | |
|---|---|---|---|---|
| | Environmental Remediation Research | Facility Operations (EMSL) | SBIR/STTR | Total Environmental Remediation |
| **FY 2010 Budget Structure** | | | | |
| Climate and Environmental Sciences | | | | |
| Environmental System Science | | | | |
| Subsurface Biogeochemical Research | 48,485 | — | — | 48,485 |
| Climate and Environmental Facilities and Infrastructure | | | | |
| EMSL Operations | — | 48,448 | — | 48,448 |
| General Purpose Equipment | 1,450 | — | — | 1,450 |
| Total, Climate and Environmental Facilities and Infrastructure | 1,450 | 48,448 | — | 49,898 |
| SBIR/STTR | — | — | 2,415 | 2,415 |
| Total Climate and Environmental Sciences | 49,935 | 48,448 | 2,415 | 100,798 |

## Climate Change Research Comparability Matrix from FY 2009 to FY 2010 Budget Structure—FY 2009 Funding

(dollars in thousands)

| | FY 2009 Budget Structure | | | | | |
|---|---|---|---|---|---|---|
| | Climate Forcing | Climate Change Modeling | Climate Change Response | Climate Change Mitigation | SBIR/STTR | Total, Climate Change Research |
| **FY 2010 Budget Structure** | | | | | | |
| Climate and Environmental Sciences | | | | | | |
| Atmospheric System Research | 25,316 | — | — | — | — | 25,316 |
| Environmental System Science | | | | | | |
| Terrestrial Ecosystem Science | 12,731 | — | 13,182 | — | — | 25,913 |
| Terrestrial Carbon Sequestration Research | — | — | — | 5,233 | — | 5,233 |
| Total, Environmental System Science | 12,731 | — | 13,182 | 5,233 | — | 31,146 |

(dollars in thousands)

| | FY 2009 Budget Structure | | | | | |
|---|---|---|---|---|---|---|
| | Climate Forcing | Climate Change Modeling | Climate Change Response | Climate Change Mitigation | SBIR/ STTR | Total, Climate Change Research |
| Climate and Earth System Modeling | | | | | | |
| Regional and Global Climate Modeling | — | 36,801 | — | — | — | 36,801 |
| Earth System Modeling | — | 25,596 | — | — | — | 25,596 |
| Integrated Assessment | — | — | 9,632 | — | — | 9,632 |
| Total, Climate and Earth System Modeling | — | 62,397 | 9,632 | — | — | 72,029 |
| Climate and Environmental Facilities and Infrastructure | | | | | | |
| ARM Operations and Infrastructure | 40,353 | — | — | — | — | 40,353 |
| Data Management and Education | 2,773 | — | 1,426 | — | — | 4,199 |
| Total, Climate and Environmental Facilities and Infrastructure | 43,126 | — | 1,426 | — | — | 44,552 |
| SBIR/STTR | — | — | — | — | 4,884 | 4,884 |
| Total Climate and Environmental Sciences | 81,173 | 62,397 | 24,240 | 5,233 | 4,884 | 177,927 |

## High Energy Physics

## Funding Profile by Subprogram

(dollars in thousands)

| | FY 2008 Current Appropriation | FY 2009 Original Appropriation | FY 2009 Adjustments | FY 2009 Current Appropriation | FY 2009 Additional Appropriation[a] | FY 2010 Request |
|---|---|---|---|---|---|---|
| High Energy Physics | | | | | | |
| Proton Accelerator-Based Physics | 371,680 | 410,343 | -7,863[b] | 402,480 | +107,990 | 442,988 |
| Electron Accelerator-Based Physics | 57,206 | 48,772 | -17,789[b] | 30,983 | +1,400 | 26,420 |
| Non-Accelerator Physics | 75,784 | 86,482 | +14,389[b] | 100,871 | +4,445 | 99,321 |
| Theoretical Physics | 60,032 | 63,036 | +1,768[b] | 64,804 | +5,975 | 67,240 |
| Advanced Technology R&D | 138,143 | 187,093 | +9,495[b] | 196,588 | +112,580 | 183,031 |
| Total, High Energy Physics | 702,845[cd] | 795,726 | — | 795,726 | +232,390 | 819,000 |

**Public Law Authorizations:**
Public Law 95–91, "Department of Energy Organization Act", 1977
Public Law 109–58, "Energy Policy Act of 2005"
Public Law 110–69, "America COMPETES Act of 2007"

## Program Overview

### Mission

The High Energy Physics (HEP) program's mission is to understand how our universe works at its most fundamental level, which is done by discovering the elementary constituents of matter and energy, probing the interactions between them, and exploring the basic nature of space and time itself.

### Background

Research in high energy physics, often called particle physics, has led to a profound understanding of the physical laws that govern matter, energy, space, and time. This understanding has been formulated in the Standard Model of particle physics, first established in the 1970s, which successfully describes all known behavior of particles and forces, often to very high precision. Nevertheless, the Standard Model is understood to be incomplete. The model fails at extremely high energies—energies just now being created in particle accelerators—and describes only a small fraction of the matter and energy filling the universe. Startling new data reveal that only about 5% of the universe is made of the normal, visible

[a] The Additional Appropriation column reflects the planned allocation of funding from the American Recovery and Reinvestment Act of 2009, P.L. 111–5. See the Department of Energy Recovery website at http://www.energy.gov/recovery for up-to-date information regarding Recovery Act funding.
[b] Reflects a reallocation of funding in accordance with the explanatory statement for the Energy and Water Development and Related Agencies Appropriations Act, 2009, P.L. 111–8.
[c] Includes $32,000,000 provided by the Supplemental Appropriations Act, 2008, P.L. 110–252.
[d] Total is reduced by $18,486,000: $16,505,000 of which was transferred to the Small Business Innovative Research (SBIR) program and $1,981,000 of which was transferred to the Small Business Technology Transfer (STTR) program.

matter described by the Standard Model. The remaining 95% of the universe consists of matter and energy whose fundamental nature remains a mystery.

A world-wide program of particle physics research is underway to explore what lies beyond the Standard Model. To this end, the HEP supports a program focused on three scientific frontiers:

- *The Energy Frontier*, where powerful accelerators are used to create new particles, reveal their interactions, and investigate fundamental forces;
- *The Intensity Frontier*, where intense particle beams and highly sensitive detectors are used to pursue alternate pathways to investigate fundamental forces and particle interactions by studying events that occur rarely in nature; and
- *The Cosmic Frontier*, where ground and space-based experiments and telescopes are used to make measurements that will offer new insight and information about the nature of dark matter and dark energy, to understand fundamental particle properties and discover new phenomena.

Together, these three interrelated and complementary discovery frontiers offer the opportunity to answer some of the most basic questions about the world around us. Because of the strong connections between the key questions in each area, successfully addressing these questions requires coordinated initiatives at each of the frontiers. The HEP program invents new technologies to answer these questions and to meet the challenges of research at the frontiers. It supports theoretical and experimental studies by individual investigators and large collaborative teams—some who gather and analyze data from accelerator facilities in the U.S. and around the world and others who develop and deploy ultra-sensitive ground- and space-based instruments to detect particles from space and observe astrophysical phenomena that advance our understanding of fundamental particle properties. Here are some of the key questions the HEP program addresses, and how we seek answers at the three frontiers:

- *Are there undiscovered principles of nature, such as new symmetries, or new physical laws?*

  The laws of quantum physics that describe elementary particles and forces are based on underlying symmetries of nature. Some of these prevail only at very high energies. A possible and well motivated new symmetry, called supersymmetry, relates particles and forces. It predicts a superpartner for every particle we know. If such superparticles exist, it may be possible to produce the lightest of them with accelerators that operate at the Energy Frontier or infer their existence from rare decays or new phenomena at the Intensity or Cosmic Frontiers.

- *How can we solve the mystery of dark energy?*

  The structure of the universe today is a result of two opposing forces: gravitational attraction and cosmic expansion. For approximately six billion years, the universe has been expanding at an accelerating rate due to a mysterious dark energy that now dominates over gravitational attraction. This energy, which permeates empty space and accelerates the expansion of the universe, must have a quantum (or particle) explanation. Dark energy was first discovered in 1998 by HEP-supported researchers (among others); more and other types of data, gathered from the Cosmic Frontier, along with new theoretical ideas, are necessary to make progress in understanding its fundamental nature.

- *Are there extra dimensions of space?*

  String theory is an attempt to unify physics by explaining particles and forces as the vibrations of sub-microscopic strings. String theory requires supersymmetry and seven extra dimensions of space. Accelerators at the Energy Frontier may find evidence for extra dimensions, requiring a completely new paradigm for thinking about the structure of space and time.

- *Do all the forces become one?*

  All the basic forces in the universe could be various manifestations of a single unified force. Unification was Einstein's great, unrealized dream, and recent advances in string theory give hope of achieving it. The discovery of superpartners or extra dimensions at Energy Frontier accelerators, or hints of them at the Intensity or Cosmic Frontiers, would lend strong support to current ideas about unification.

- *Why are there so many kinds of particles?*

  Three different families of quarks and leptons have been discovered, all at DOE national laboratories. Does nature somehow require that there are only three, or are there more? Moreover, the various quarks and leptons have widely different masses and force couplings. These differences suggest there may be an undiscovered explanation that unifies quarks and leptons, just as the discovery of quarks simplified the zoo of composite particle states discovered in the 1960s. Detailed studies that employ Energy Frontier accelerators, as well as precision measurements made at Intensity Frontier facilities, may provide the dramatic insights into this complex puzzle.

- *What is dark matter? How can we make it in the laboratory?*

  Most of the matter in the universe is invisible. We can detect its existence only through its gravitational interactions with normal matter. This dark matter is thought to consist of exotic particles (relics) that have survived since the Big Bang. Experiments are being mounted to try to directly detect these exotic particles, via direct observations of relic dark matter at the Cosmic Frontier or by producing them at Energy Frontier accelerators that briefly recreate the conditions of the Big Bang.

- *What are neutrinos telling us?*

  Of all the known particles, neutrinos are perhaps the most enigmatic and the most elusive. The three known varieties of neutrinos were all discovered by HEP researchers working at U.S. facilities. Trillions pass through the Earth every moment with little or no interaction. Their detection requires intense neutrino sources and large detectors. Their tiny masses may imply new physics and provide important clues to the unification of forces. Naturally occurring neutrinos are produced by cosmic ray interactions with the Earth's atmosphere, by supernovae, and in the interior of stars. These can be studied at the Cosmic Frontier. They can also be studied at the Intensity Frontier using intense neutrino sources such as nuclear reactors and advanced accelerators.

- *How did the universe come to be?*

  Our universe began with a massive explosion known as the Big Bang, followed by a burst of expansion of space itself. The universe then expanded more slowly and cooled, which allowed the formation of stars, galaxies, and ultimately life. Understanding the very early evolution of the universe will require a breakthrough in physics: the theoretical reconciliation of quantum mechanics with gravity. The history of the universe is explored at all three Frontiers.

- *What happened to the antimatter?*

  The universe appears to contain very little antimatter. Its existence is transient. It is continually produced by naturally occurring nuclear reactions only to undergo near immediate annihilation. The Big Bang, however, should have produced equal amounts of both matter and antimatter. This is borne out by the study of high-energy collisions in the laboratory. Precise Energy and Intensity Frontier accelerator-based measurements of the subtle asymmetries present in the weak nuclear interaction may shed light on how the matter-antimatter asymmetry arose.

## Subprograms

The High Energy Physics program is divided into five subprograms that are organized around the tools and facilities they employ (e.g., an electron accelerator or cosmic ray detector), and/or the knowledge and technology they develop (e.g., superconducting radio frequency cavities or computational capabilities):

- The *Proton Accelerator-Based Physics subprogram* exploits two major applications of proton accelerators. Due to the high energy of the collisions at the Tevatron Collider (2 TeV) and the Large Hadron Collider (LHC, 14 TeV) and the fact that the particles interact differently at different energies, these facilities can be used to study a wide variety of scientific issues. Proton accelerators are also capable of producing, by colliding intense proton beams into fixed targets, large samples of other particles (e.g., antiprotons, K mesons, muons, and neutrinos) which can be formed into beams for experiments. The proposed Intensity Frontier program utilizes the high-power proton beam at Fermilab to produce intense secondary beams of neutrinos and muons for world-leading experiments.
- The *Electron Accelerator-Based Physics subprogram* utilizes accelerators with high-intensity and ultra-precise electron beams to create and investigate matter at its most basic level. Since electrons are light, point-like particles (unlike protons, which are relatively heavy composites of quarks and gluons) they are well-suited to precision measurements of particle properties and exacting beam control. Over the last few years, the electron B-factory at the SLAC National Accelerator Laboratory has provided sensitive searches for new phenomena and definitive measurements of the behavior of matter and antimatter observed in the decay products of B-mesons. The next-generation Energy Frontier accelerator after the LHC is likely to be a high-energy electron facility that can probe LHC discoveries in detail.
- The *Non-Accelerator Physics subprogram* provides U.S. leadership in the study of those topics in particle physics that cannot be investigated with accelerators, or are best studied by other means. These activities have provided experimental data, new ideas, and techniques complementary to those provided by accelerator-based research; some of the earliest discoveries in particle physics were due to the production of previously unobserved particles in high-energy cosmic rays. Scientists in this subprogram investigate topics such as dark matter, dark energy, neutrino properties, proton decay, the highest energy gamma rays, and primordial antimatter. Some of the non-accelerator particle sources used in this research are cosmic rays, neutrinos from commercial nuclear power reactors, the Sun, and galactic supernovae.
- The *Theoretical Physics subprogram* provides the vision and mathematical framework for understanding and extending the knowledge of particles, forces, space-time, and the universe. This program supports activities that range from detailed calculations of the predictions of the Standard Model to advanced computation and simulations to solve otherwise intractable problems. Theoretical physicists play key roles in determining which experiments to perform and explaining experimental results in terms of underlying theories that describe the interactions of matter, energy, and space-time.
- The *Advanced Technology R&D subprogram* develops the next generation of particle accelerator and detector technologies for the future advancement of high-energy physics and other sciences, supporting world-leading research in the physics of particle beams, fundamental advances in particle detection, and R&D on new technologies and research methods appropriate for a broad range of scientific disciplines.

## Benefits

Seeking answers to big questions drives basic research. It appeals to our deepest human nature. However, the new technologies created to answer the questions above, and the knowledge acquired in their pursuit, also yield substantial benefits of a more tangible nature for society as a whole. The continuous improvement of accelerator and detector technology necessary to pursue high energy physics as well as the scale of the science itself, have had transformative impacts on the Nation's economy, security, and society. The contributions of high energy physics to the underlying technologies now used in medicine, science, industry, homeland and national security, as well as for workforce training, are well known. (For more information, visit http://www.science.doe.gov/hep/benefits)

Looking to the future, HEP's ongoing and future development of accelerator, detector, electronics, and magnet technologies is anticipated to have significant impact in a number of areas: medical treatment and diagnosis—where new, more cost-efficient particle accelerators, detectors, and magnets for cancer treatment and diagnosis should emerge; homeland and national security—where particle accelerators and detectors developed for high energy physics research have the potential for border detection and non-proliferation verification; industry—where, for example, superconducting cables being developed for next generation magnets for high energy physics research could be used to transmit, with minimal power losses, far more electricity than conventional cables; internet grid development—where the developments of the international grid capability for data analysis of the large detectors at the LHC may result in a paradigm change in the handling of huge data sets; and other scientific fields—where the underlying R&D needed for next-generation particle accelerators and detectors will be carried out by HEP's accelerator and advanced technology science programs.

An important benefit to the Nation provided by the HEP program is the recruitment and training of a highly motivated, highly trained scientific and technical work force. In particle physics, roughly one sixth of those completing doctoral degrees ultimately pursue careers in high energy physics research. The rest find their way to diverse sectors of the national economy such as industry, national defense, information technology, medical instrumentation, electronics, communications, and biophysics—wherever the workforce requires highly developed analytical and technical skills, the ability to work in large teams on complex projects, and the ability to think creatively to solve unique problems.

## Program Planning and Management

- *Advisory and Consultative Activities*

  To ensure that resources are allocated to the most scientifically promising experiments, DOE and its national laboratories actively seek external input using a variety of advisory bodies. The High Energy Physics Advisory Panel (HEPAP), jointly chartered by the DOE and the National Science Foundation (NSF), provides advice regarding the scientific opportunities and priorities of the national high energy physics research program. HEPAP or one of its subpanels undertakes special studies and planning exercises in response to specific charges from the funding agencies.

  A HEPAP subpanel called the Particle Physics Project Prioritization Panel (P5) was formed to assess and prioritize scientific opportunities and proposed projects. HEPAP subpanels are also convened to review progress and/or future plans in particular research areas or elements of the HEP program. In 2007, HEPAP/P5 was charged to examine the options for mounting a world-class U.S. particle physics program at various funding levels. This HEPAP report[a] was submitted in June 2008 and has

[a] The full HEPAP report is available at http://www.science.doe.gov/hep/files/pdfs/P5_Report%2006022008.pdf.

provided important input for setting programmatic priorities for the HEP program. Many of the recommendations contained in the report are implemented in this budget request.

The Astronomy and Astrophysics Advisory Committee (AAAC) now reports on a continuing basis to the DOE, as well as to the NSF and National Aeronautics and Space Administration (NASA), with advice on the direction and management of the national astronomy and astrophysics research programs. The AAAC operates similarly to HEPAP and the two advisory bodies have been charged to form joint task forces or subpanels to address research issues at the intersection of high energy physics and astrophysics and astronomy, such as dark energy and dark matter.

The HEP program has also instituted Committee of Visitors (COV) that provides an independent review of its responses to proposals and its research management process, as well as an evaluation of the quality, performance, and relevance of the research portfolio and an assessment of its breadth and balance. The second triennial HEP COV review took place in summer 2007. The 2007 COV report[a] has 18 specific recommendations relating primarily to staffing, grants review and processing, and project management. HEP has completed six of the recommendations, particularly in regard to staffing; seven recommendations are in-process; and five recommendations are on-going.

- *Review and Oversight*

  The HEP program office reviews and provides oversight for its research portfolio. All university research proposals are subjected to a multistage review process to ensure high quality research and relevance to achieving the goals of the national program. Proposals to DOE for grant support are peer-reviewed by external technical experts, following the guidelines established by 10 CFR Part 605.

  Following recommendations of the 2007 COV, HEP implemented a new review process for high energy physics research and basic technology R&D efforts at DOE laboratories. Laboratory high energy physics research or technology R&D groups are peer-reviewed triennially on a rotating basis, using the same criteria established for the university reviews. This is a comparative review that assesses the relative strengths and weaknesses of the various laboratory groups in particular research subfields. In FY 2010, the Electron Accelerator-Based and Non-Accelerator Physics subprograms will be reviewed.

## Basic and Applied R&D Coordination

Many of the broader applications of technology originally developed for HEP research have been serendipitous. In order to provide a more direct connection between fundamental accelerator technology and applications, the HEP program is sponsoring a workshop in 2009 to assess the R&D needs of these various stakeholders and identify the significant challenges that could benefit from future technology R&D initiatives. An output of this workshop will be a report that articulates the role of accelerators in the nation's efforts in science, medicine, national security, and industry; identifies the opportunities and research challenges for next generation accelerators; suggests the most promising avenues for new or enhanced R&D efforts; and develops a path forward to stronger coordination between basic and applied research. HEP will use this report to develop a strategic plan for accelerator technology R&D that recognizes its broader societal impacts.

## Budget Overview

The HEP program addresses the fundamental questions about the nature of the universe by balancing the scientific priorities of the research community with the constraints of the facilities, tools, and resources

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[a] The 2007 COV report and HEP's response are available at http://www.science.doe.gov/SC-2/COV-HEP/HEP_Reviews.htm.

available. Research facilities for high energy physics generally require significant investments over many years and the coordinated efforts of international teams of scientists and engineers to realize accelerators and detectors that push the frontiers of Energy, Intensity and Cosmic exploration.

The HEP program, with input from the scientific community, has developed a long-range plan which maintains a leadership role for the U.S. within this global context. In this plan there is a shift of focus from the operation of the facilities built at the end of the 1990s (SLAC B-factory, Tevatron Collider) to the design and construction of new research capabilities, meanwhile maintaining a world-leading scientific program and identifying targeted long-range R&D for the future. This strategic plan allows the Nation to play an important role at all three frontiers of particle physics:

**The Energy Frontier:** The Tevatron Collider at Fermi National Accelerator Laboratory (Fermilab) continues operations in FY 2010. Its record-breaking performance over the last few years means that it remains competitive with the LHC, for significant discoveries. The primary scientific goals of the HEP program over the next five years are to enable these discoveries—for example, the Higgs boson and supersymmetric particles—either at the Tevatron or the LHC. The first beam collisions at the LHC are anticipated in the fall of 2009. Support for LHC detector operations, maintenance, computing, and R&D is necessary to maintain a U.S. leadership role in the LHC program.

The HEP strategic plan includes U.S. participation in the LHC accelerator and detector upgrades, currently envisioned as a two-stage process. Phase I, which is planned to begin fabrication in FY 2010, provides a two-fold increase in the LHC luminosity (a measure of the number of physics interactions per second), which will significantly lower statistical uncertainties and improve the chances of observing rare events. Data from Phase I will guide the choice of the most promising physics to pursue in Phase II, which includes a ten-fold increase in luminosity. To handle the increased data rate, LHC detectors will also be upgraded. Physics results from the LHC will also help guide research and development for the proposed International Linear Collider (ILC). The ILC's internationally-coordinated R&D plan will address the current technical challenges and complete a pre-conceptual design by 2012.

**The Intensity Frontier:** The Neutrinos at the Main Injector (NuMI) beamline at Fermilab will operate in its current configuration through FY 2011 for ongoing neutrino experiments and then will be subject to a year-long upgrade from approximately 400 kW to 700 kW of beam power for the NuMI Off-Axis Neutrino Appearance (NOνA) experiment. The NOνA project will enable key measurements of neutrino properties; it is under construction and will be in full operation in 2014. During FY 2010, R&D for proposed new experiments using the NuMI beam and other auxiliary beamlines, such as the Long Baseline Neutrino oscillation experiment (LBNE) and the Muon to Electron Experiment (Mu2e), will be underway so these experiments can be ready for operation before the end of the next decade.

Significant results from the neutrino experiments currently being implemented (e.g., NOνA, the Reactor Neutrino Detector at Daya Bay, and other precision measurements in which the U.S. is involved) will emerge over the next decade, keeping the U.S. at the forefront of these studies and determining the future direction of this research. At the same time, the infrastructure needed for a world-leading program in neutrino studies and for rare decay searches in the U.S. will have been put into place. This plan will provide the U.S. with a robust, continuous program of world-leading physics at the Intensity Frontier centered at Fermilab in the decade after the end of the Tevatron Collider program.

**The Cosmic Frontier:** DOE is partnering with the NASA and the NSF in world class, space-based and ground-based particle astrophysics observatories for exploration of the Cosmic Frontier. HEP and NASA are presently jointly supporting analysis of data from NASA's Fermi Gamma-ray Space Telescope (FGST) that detects gamma-rays emanating from astrophysical sources, and HEP continues support for commissioning and integration activities for the Alpha Magnetic spectrometer (AMS) experiment which is on NASA's Space Shuttle manifest for launch in 2010. HEP is collaborating with NSF on the ground-based Dark Energy Survey (DES) telescope, currently in fabrication, as well as R&D aimed at developing large, next-generation survey telescopes that can significantly advance our knowledge of dark energy. HEP will continue to collaborate with NSF on a phased program of research and technology development that is designed to directly detect dark matter particles (rather than indirectly observe their effects on normal matter) using ultra-sensitive detectors located underground.

**Significant Program Shifts**

Following the recommendations of HEPAP, a continued leadership role for the U.S. HEP program requires investments in new facilities to exploit the scientific opportunities at the research frontiers. In this budget request, there is a significant increase in funding for fabrication of new major items of equipment to enable future discoveries.

**Strategic and GPRA Unit Program Goals**

The HEP program has one Government Performance and Results Act (GPRA) Unit Program Goal which contributes to Strategic Goals 3.1 and 3.2 in the "goal cascade."

- GPRA Unit Program Goal 3.1/2.46.00: Explore the Fundamental Interactions of Energy, Matter, Time and Space - Understand the unification of fundamental particles and forces, and the mysterious forms of unseen energy and matter that dominate the universe; search for possible new dimensions of space; and investigate the nature of time itself.

**Contribution to GPRA Unit Program Goal 3.1/2.46.00, Explore the Fundamental Interactions of Energy, Matter, Time and Space**

HEP contributes to this goal by advancing our understanding of the basic constituents of matter and the forces between them, deeper symmetries in the laws of nature at high energies, and mysterious phenomena that pervade the universe, such as dark energy and dark matter. HEP uses particle accelerators and very sensitive detectors to study fundamental particle interactions at the highest possible energies. Because particle physics is deeply connected to the origin and evolution of the universe itself, the HEP program also supports non-accelerator studies of cosmic particles and phenomena including experiments conducted deep underground, on mountains, or in space. This research at the frontier of science may discover new particles, forces, or undiscovered dimensions of space and time; explain how matter came to have mass; and reveal the underlying nature of the universe. In particular, the HEP program seeks to identify the mysterious dark matter that holds galaxies together and the even more mysterious dark energy that is stretching space apart; explain why there is any matter in the universe at all; and show how the tiniest constituents of the universe play a leading role in shaping its birth, growth, and ultimate fate. Our goals in FY 2010 address all of these questions.

The FY 2010 budget request places high priority on operations, upgrades, and infrastructure for the two major HEP user facilities: the Tevatron Collider and Neutrinos at the Main Injector (NuMI) at Fermilab, to produce maximum scientific data to address these fundamental questions.

In 2004, the HEPAP established the following indicators for specific long-term (10 year) goals in scientific advancement to which the HEP program is committed. They do not necessarily represent the research goals of individual experiments in the field. The order of the indicators corresponds roughly to current research priorities, and is meant to be representative of the program, not comprehensive.

- Measure the properties and interactions of the heaviest known particle (the top quark) in order to understand its particular role in the Standard Model, our current theory of particles and interactions.
- Measure the matter-antimatter asymmetry in many particle decay modes with high precision.

- Discover or rule out the Standard Model Higgs particle, thought to be responsible for generating the mass of elementary particles.
- Determine the pattern of the neutrino masses and the details of their mixing parameters.
- Confirm the existence of new supersymmetric (SUSY) particles or rule out the minimal SUSY Standard Model of new physics.
- Directly discover or rule out new particles that could explain the cosmological "dark matter."

## Annual Performance Results and Targets

| FY 2005 Results | FY 2006 Results | FY 2007 Results | FY 2008 Results | FY 2009 Targets | FY 2010 Targets |
|---|---|---|---|---|---|
| GPRA Unit Program Goal 3.1/2.46.00—Explore the Fundamental Interactions of Energy, Matter, Time and Space | | | | | |
| All HEP Facilities | | | | | |
| Maintained and operated HEP facilities such that unscheduled downtime was on average less than 20% of the total scheduled operating time. [Met Goal] | Maintained and operated HEP facilities such that unscheduled downtime was on average less than 20% of the total scheduled operating time. [Goal Not Met | Maintained and operated HEP facilities such that unscheduled downtime was on average less than 20% of the total scheduled operating time. [Met Goal]] | Achieve greater than 80% average operation time of the scientific user facilities (the Fermilab Tevatron and the Stanford Linear Accelerator (SLAC) B-factory) as a percentage of the total scheduled annual operating time. [Met Goal] | Achieve greater than 80% average operation time of the scientific user facility (the Fermilab Tevatron) as a percentage of the total scheduled annual operating time. | Achieve greater than 80% average operation time of the scientific user facility (the Fermilab Tevatron) as a percentage of the total scheduled annual operating time. |
| Proton Accelerator-Based Physics/Facilities | | | | | |
| Delivered data as planned within 20% of the baseline estimate (390 $pb^{-1}$) to CDF and D-Zero detectors at the Tevatron. [Met Goal] | Delivered data as planned within 20% of the baseline estimate (675 $pb^{-1}$) to CDF and D-Zero detectors at the Tevatron.[Met Goal] | Delivered data as planned within 20% of the baseline estimate (800 $pb^{-1}$) to CDF and D-Zero detectors at the Tevatron. [Met Goal] | Deliver within 20% of baseline estimate a total integrated amount of data (800 $pb^{-1}$) to CDF and D-Zero detectors at the Tevatron. [Met Goal] | Deliver within 20% of baseline estimate a total integrated amount of data (1,200 $pb^{-1}$) to CDF and D-Zero detectors at the Tevatron. | Deliver within 20% of baseline estimate a total integrated amount of data (1,700 $pb^{-1}$) to CDF and D-Zero detectors at the Tevatron. |
| | Delivered data as planned within 20% of the baseline estimate ($1x10^{20}$ protons on target) for the MINOS experiment using the NuMI facility.[Met Goal] | Delivered data as planned within 20% of the baseline estimate (1.5 $x10^{20}$ protons on target) for the MINOS experiment using the NuMI facility. [Met Goal] | Measure within 20% of the total integrated amount of data (2.0 $x10^{20}$ protons on target) delivered to the MINOS detector using the NuMI facility. [Met Goal] | Measure within 20% of the total integrated amount of data (2.7 $x10^{20}$ protons on target) delivered to the MINOS detector using the NuMI facility. | Measure within 20% of the total integrated amount of data (2.7 $x10^{20}$ protons on target) delivered to the MINOS detector using the NuMI facility. |
| Electron Accelerator-Based Physics/Facilities | | | | | |
| Delivered data as planned within 20% of baseline estimate (45 $fb^{-1}$) to the BaBar detector at the SLAC B-factory. [Met Goal] | Delivered data as planned within 20% of baseline estimate (50 $fb^{-1}$) to the BaBar detector at the SLAC B-factory. [Met Goal] | Delivered data as planned within 20% of the baseline estimate (100 $fb^{-1}$) to the BaBar detector at the SLAC B-factory.[Met Goal] | Delivered data as planned within 20% of the baseline estimate (54 $fb^{-1}$) to the BaBar detector at the SLAC B-factory. [Met Goal] | | |
| Construction/Major Items of Equipment | | | | | |
| Maintained cost and schedule milestones for upgrades and new major construction projects within 10% of baseline estimates. [Met Goal] | Maintained cost and schedule milestones for upgrades and new major construction projects within 10% of baseline estimates. [Met Goal] | Maintained cost and schedule milestones for major items of equipment and new construction projects within 10% of baseline estimates. [Met Goal] | Achieve less than 10% for both the cost-weighted mean percentage variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects. [Met Goal] | Achieve less than 10% for both the cost-weighted mean percentage variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects. | Achieve less than 10% for both the cost-weighted mean percentage variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects. |

## Proton Accelerator-Based Physics

## Funding Schedule by Activity

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Proton Accelerator-Based Physics | | | |
| Research | 122,882 | 125,734 | 127,228 |
| Facilities | 248,798 | 276,746 | 315,760 |
| Total, Proton Accelerator-Based Physics | 371,680 | 402,480 | 442,988 |

### Description

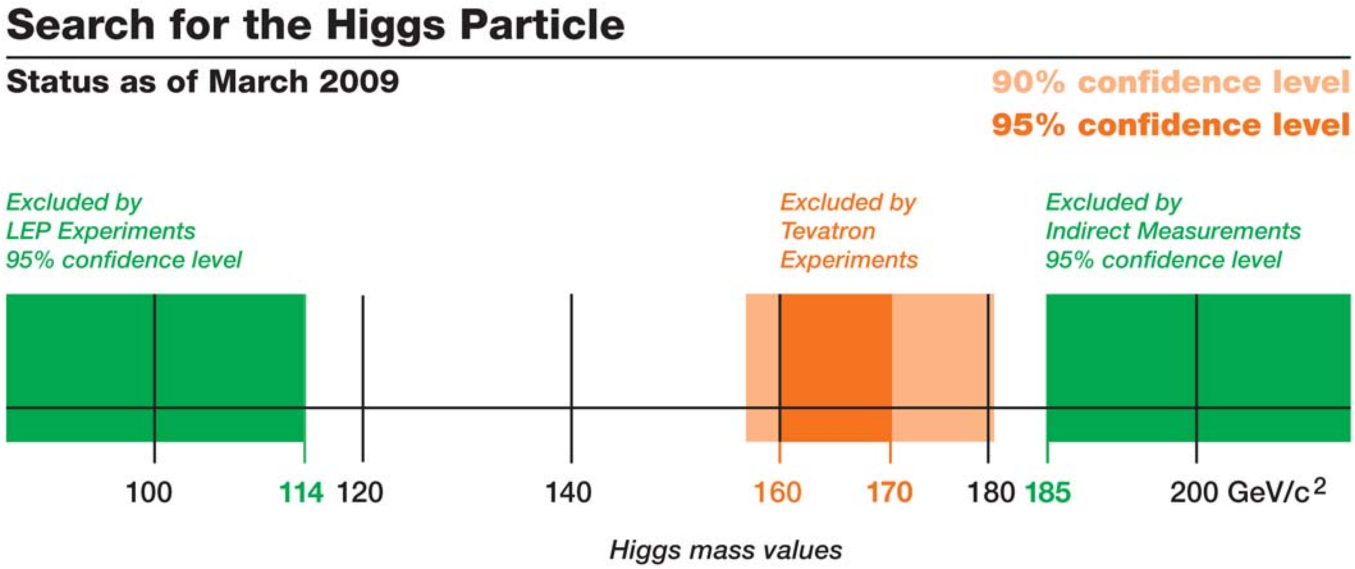
The Proton Accelerator-Based Physics subprogram will determine whether the Standard Model correctly predicts the mechanism that generates mass for all fundamental particles and will search for the first clear evidence of new physics beyond the Standard Model. This experimental research program also includes precise, controlled measurements of basic neutrino properties performed at accelerator facilities. These measurements, performed with neutrino beams generated from primary proton beams, will provide important clues and constraints to the new world of matter and energy beyond the Standard Model.

The most immediate goal on the particle physics roadmap is to fully understand the unification of the electromagnetic and weak nuclear interactions into a single, electroweak force at the Energy Frontier. The fact that this force is unified at high energies but separated or their symmetry broken at lower energies gives rise to masses for the fundamental particles. Originally it was proposed that a single Higgs boson was the solution to this problem and hence the source of mass. Newer theories, however, such as supersymmetry and extra hidden dimensions, may also solve this problem without or with one or more Higgs bosons. It will take experimental results to decide between competing theories. One expectation, however, is clear: new physics must occur at the Energy Frontier. Whether the Tevatron or the LHC is the first accelerator to observe this new physics will depend on the configuration that nature has chosen for these phenomena.

The Energy Frontier will begin to shift from the U.S. to Europe with the first beam collisions at LHC planned in late FY 2009. However, it is likely that first LHC physics results won't appear until FY 2011 due to the expected difficulty of commissioning such large and complex accelerator and detector systems. In contrast, after many years of operation, the Fermilab experiments are able to rapidly deliver physics results, providing a window of opportunity for Fermilab to make discoveries at the Energy Frontier during initial LHC operations.

### Selected FY 2008 Accomplishments

- For the first time since the Large Electron-Positron (LEP) collider at CERN last operated in 2000, researchers are again treading on unexplored Higgs territory with the Tevatron Collider experiments at Fermilab. Recently, combined results from the Tevatron Collider experiments have started to exclude a region of Higgs mass between 160 and 170 GeV/$c^2$ (see figure below). As more data is collected at the Tevatron, either this exclusion region will expand or the first possible hints of the Higgs boson will appear.




- The Tevatron Collider experiments, CDF and D-Zero, have observed rare Standard Model processes such as double Z boson production, simultaneous W and Z boson production, and single top quark production. The observation of these rare processes is a necessary precursor for the discovery of the Higgs boson. In addition, the Tevatron has also recently produced the most precise measurements of top quark and W boson parameters, which are used to further constrain new physics theories. The innovative analysis methods employed by CDF and D-Zero scientists and the thorough understanding of detector performance and backgrounds displayed in these results bode well for future discoveries.
- In the area of neutrino physics, the Main Injector Neutrino Oscillation Search (MINOS) experiment at Fermilab has produced new measurements that include the best measurement of the mass difference between neutrinos and a competitive measurement of the mixing angle that determines the neutrino oscillations.

**Detailed Justification**

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| **Research** | **122,882** | **125,734** | **127,228** |

The major activities under the Proton Accelerator-Based Physics subprogram are the research programs using the CDF and D-Zero detectors at the Tevatron at Fermilab, the neutrino research program using the NuMI/MINOS detectors located at Fermilab and at the Soudan Mine site in Minnesota, and the research programs of ATLAS and CMS at the Large Hadron Collider (LHC) at CERN.

The research program using the Tevatron Collider at Fermilab is being carried out by a collaboration composed of 1,400 scientists from Fermilab, Argonne National Laboratory (ANL), Brookhaven National Laboratory (BNL), 56 U.S. universities, and institutions in over 20 foreign countries. The major effort in FY 2010 will be the collection of data with the CDF and D-Zero detectors. The physics issues to be addressed include searches for the Higgs boson, supersymmetry, or other new phenomena; B meson studies including charge-parity (CP) violation; and precision measurements of the top quark and the W boson properties. In particular, the direct experimental searches for a Standard Model Higgs

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |

boson with a mass in the range expected (based on other indirect experimental data) will require the entire Tevatron data set. The Tevatron Collider experiments will collect data in FY 2010 to provide the two experiments access to a significant region of the expected Higgs mass range.

The research program using the NuMI/MINOS Facilities at Fermilab and the Soudan Mine is being carried out by a collaboration that includes 250 scientists from Fermilab, ANL, BNL, Lawrence Livermore National Laboratory (LLNL), 16 U.S. universities, and institutions in four foreign countries. The major effort in FY 2010 will be data collection and analysis, along with optimizing accelerator performance to improve beam intensity for higher statistics measurements. The experiment is planned to run through FY 2011 to achieve its ultimate sensitivity, approximately a factor of two improvement over its current result and will search for the as-yet unseen oscillation of muon neutrinos to electron neutrinos.

In FY 2010, U.S. researchers will play a leadership role in the physics discoveries at the high energies enabled by the LHC. Achieving this goal requires effective integration of U.S. researchers in the LHC detector calibration and data analysis efforts, and implementation and optimization of the U.S. data handling and computing capabilities needed for full participation in the LHC research program. Maintenance of U.S.-supplied detector elements for LHC experiments at CERN will continue.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **Grants Research** | **55,365** | **57,025** | **57,725** |

The grant-based HEP experimental research program consists of groups at more than 60 universities performing experiments at proton accelerator facilities. Grant-based scientists typically constitute about 50–75% of the personnel needed to create, run, and analyze an experiment, and they usually work in collaboration with other university and laboratory groups. Grant-based research efforts are selected based on peer review, and funded at levels commensurate with the effort needed to carry out the experiments.

In FY 2010, the grant research effort is maintained at the FY 2009 level. LHC research activities will be supported while maintaining participation in the Tevatron and neutrino physics programs. Strong participation of university physicists is needed to carry out the collider and neutrino program at the Tevatron during FY 2010. There will be healthy scientific competition between completion of Run II of the Tevatron Collider program and commencement of the LHC experiments, although the level of this competition will depend on how quickly the LHC will be brought into operation. Some migration of U.S. university researchers from the LHC back to the Tevatron Collider program has been observed in FY 2009 due to the delayed startup of the LHC. The detailed funding allocations will take into account the quality of research as well as the involvement of grant-based research groups in the targeted physics research activities.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **National Laboratory Research** | **66,303** | **67,771** | **68,565** |

Proton accelerator research activities concentrate on experiments at the Tevatron complex (collider and neutrino physics programs) at Fermilab and the LHC at CERN. The HEP program will conduct a comparative peer review of laboratory research groups in this subprogram in 2009.

In FY 2010, U.S. laboratory physicists will participate in and play important roles in the A large Toroidal LHC ApparatuS (ATLAS) and Compact Muon Solenoid (CMS) experiments, as LHC operations and data analysis move past the commissioning phase into steady-state operations. Strong involvement of physicists from the national laboratories will also be needed to carry out

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|

(dollars in thousands)

the research program at the Tevatron during FY 2010. The HEP program will monitor progress in these areas and balance resources in order to optimize the national program.

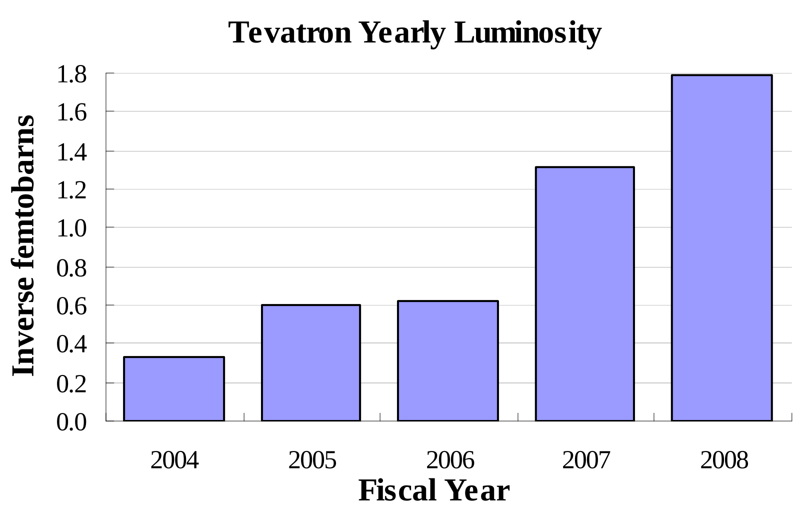
The Fermilab research program includes data collection and analysis of the CDF, D-Zero, and MINOS experiments; the CMS research and computing program; and research related to the new neutrino initiatives, such as the NOνA and MINERνA experiments. Research at LBNL consists of a large and active group in the ATLAS research program. The BNL research group will focus on the ATLAS research and computing program, with a small effort on D-Zero and a small effort related to future neutrino initiatives. The research group at ANL will be working primarily on the ATLAS research and computing program, data taking and analysis of the MINOS detector, and research related to the new neutrino initiatives, such as the NOνA experiment. A research group from SLAC has joined the ATLAS experiment and is expanding its efforts in order to take on important roles in LHC research and data analysis.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **University Service Accounts** | **1,214** | **938** | **938** |

University Service Accounts facilitate the support of university groups working at accelerator facilities. This activity provides funding for these groups to purchase needed equipment and services from the laboratories with a minimum of time and cost overhead. Currently, 45 university groups maintain service accounts at Fermilab and at BNL. Funding for these university service accounts is maintained at the FY 2009 level, reflecting the anticipated need.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **Facilities** | **248,798** | **276,746** | **315,760** |
| ▪ **Proton Accelerator Complex Operations** | **132,688** | **128,485** | **123,985** |

Fermilab operations include running the Tevatron accelerator complex for both collider and neutrino physics programs comprised of two collider detectors and a neutrino experiment, respectively. The performance of the Tevatron collider has continued to improve as the laboratory staff has learned to effectively exploit the upgrades that were completed in FY 2006. Tevatron performance improved significantly in FY 2007 and FY 2008 as can be seen in the plot below. The vertical axis represents the amount of beam delivered to the experiments.



| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| | (dollars in thousands) | | |

Some of the increase in luminosity in FY 2008 was due to additional running time that was scheduled to maximize the integrated luminosity before the first beam collisions at the LHC. Performance in FY 2009 and FY 2010 should plateau around 2 inverse femtobarns per year, so the total delivered luminosity for Run II will be about two-thirds higher than the total recorded by the end of FY 2008.

In FY 2010, the decrease of funding in this category reflects the fact that stable running has been achieved and that less person-power is needed to run the accelerator. Increased automation of data collection with the CDF and D-Zero detectors has also reduced person-power required for detector operations.

Operations of the Tevatron complex include simultaneous provision of beam for fixed target and collider programs. This dual running mode is necessary for the MINOS experiment, which uses neutrinos from the NuMI beamline.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| Proton Accelerator Complex[a] | | | |
| Achieved Operating Hours | 6,500 | N/A | N/A |
| Planned Operating Hours | 5,040 | 5,040 | 5,400 |
| Optimal hours (estimated) | 5,400 | 5,400 | 5,400 |
| Percent of Optimal Hours | 120% | 93% | 100% |
| Unscheduled Downtime | 16% | N/A | N/A |
| Total Number of Users | 2,160 | 2,160 | 2,000 |

- **Proton Accelerator Complex Support** **17,930** **16,662** **14,161**

This category includes funds for general plant projects (GPP) and other infrastructure improvements at Fermilab, funding for accelerator improvements, experimental computing expansion and other detector support. A backlog of GPP projects is being addressed with 2009 Recovery Act funding, and overall needs for small accelerator improvements are reduced as the Tevatron Collider is in steady-state operations.

- **Proton Accelerator Facility Projects** **19,584** **45,177** **80,173**
  - **Current Facility Projects** **19,184** **32,666** **59,800**

After the completion of Tevatron Collider Run II, it will be possible to adapt portions of the existing collider complex to support operations of the NuMI beam-line at even higher intensity. Reconfiguration of the recycler, which currently serves as a storage ring for antiprotons, can raise the beam power to the NuMI target from 400 kW to 700 kW. Improvements to the cooling, shielding, and power supplies in the booster, main injector, and NuMI beam-line would also be done to support the higher beam intensity.

Since the increase in neutrino intensity that can be achieved with this reconfiguration will be very important to support the physics goals of the NOνA detector, this collection of upgrades and

[a] Tevatron and NuMI operations run in parallel.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |

improvements has been included as part of the scope of the NOνA project in order to ensure appropriate project management oversight and integration.

The NOνA detector is optimized to identify electron-type neutrinos and, using the NuMI beam from Fermilab, it will observe for the first time the transformation of muon-type neutrinos into electron-type neutrinos. It will also make important indirect measurements from which we may be able to determine the mass hierarchy of the three known neutrino types (i.e., whether there are two light and one heavier type neutrinos or vice versa). This will be a key piece of information that will help determine the currently unknown masses of neutrinos. The project includes the very large far detector (approximately a football-field size footprint that is five stories high), the far detector enclosure, its associated electronics and data acquisition system, and a small near detector on the Fermilab site. The project baseline was approved in September 2008. In FY 2010, TEC funds provided ramp up significantly. Fabrication will be completed in FY 2014, and the detector will start taking data in the same fiscal year.

Also included in this category is $800,000 to complete fabrication of MINERνA. This small experiment in the MINOS near detector hall at Fermilab will measure the rates of neutrino interactions with ordinary matter. MINERνA will use the powerful NuMI beam to measure these interactions with greater precision than previous experiments. Results from MINERνA will have a significant impact on MINOS and other neutrino experiments, including NOνA. This project is planned to be completed and taking data in FY 2010.

| | | | |
|---|---|---|---|
| • **Future Facility Projects R&D** | **400** | **12,511** | **20,373** |

In FY 2010, R&D and conceptual design is supported for a long baseline neutrino experiment, recommended by HEPAP/P5 as a high priority initiative at the Intensity Frontier. The experiment will require both a new neutrino beam and large detector. The detector is envisioned to be significantly larger than the NOνA detector, and located over 1000 kilometers from the neutrino beam. The large increase in size will greatly improve sensitivity to key neutrino parameters. A Critical Decision 1 (Selection of Alternatives) approval is expected by the end of FY 2010 or early FY 2011.

Pre-conceptual R&D for possible future projects that utilize the Fermilab facility is also funded in this category. Specifically, pre-conceptual R&D for an experiment to search for lepton flavor violation by observing the conversion of a muon into an electron within the electromagnetic field of a nucleus is supported, based on the recommendation of HEPAP/P5.

In addition, pre-conceptual R&D on a superconducting 8 GeV linac is supported. This linac would provide the beam power needed to continue high intensity experiments using the Fermilab accelerator complex. It would replace the current linac and booster accelerators at Fermilab, which are over 35 years old, and upgrade the beam power from 700 kilowatts (as planned for NOνA) to 2000 kilowatts.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| ▪ **Large Hadron Collider Support** | **65,572** | **74,437** | **86,520** |

U.S. involvement in this effort has been regularly endorsed by HEPAP and by a National Academies report (EPP 2010 [a]). The U.S. LHC effort is jointly supported by DOE and NSF and is one of HEP's highest priorities. HEP resources will be used for LHC software and computing, as well as operations and maintenance of the U.S.-built systems that are part of the LHC detectors. The U.S. also participates in accelerator commissioning and accelerator physics studies that use the LHC, along with R&D for potential future upgrades to both the accelerator and its detectors.

| | | | |
|---|---|---|---|
| • **LHC Accelerator Research** | **11,918** | **15,500** | **12,390** |

The U.S. LHC Accelerator Research Program (LARP) is supported solely by DOE. It will continue to focus its R&D effort on the production of full-scale, accelerator-quality magnets that sustain the highest possible magnetic fields. Special instrumentation that will play an important role during the LHC accelerator commissioning and operation phase, such as beam collimation and monitoring systems, is also being developed. In FY 2009, LARP has delivered a luminosity monitoring system to CERN for the LHC. This R&D effort will provide important technical data to CERN for management decisions on possible future LHC accelerator upgrades to increase luminosity. In FY 2009, funding was provided for R&D on prototypical LHC interaction region magnets composed of optimized niobium-tin ($Nb_3Sn$) superconductor material. The development of these magnets is in preparation for U.S. participation in a second phase of upgrades to LHC.

| | | | |
|---|---|---|---|
| • **LHC Detector Support** | **53,654** | **56,437** | **58,130** |

Funding is provided for operations and maintenance of the U.S.-built detector subsystems. Installation of the hardware was completed in 2008 and will be commissioned with cosmic ray data until the first LHC beam collisions occur. This effort will support the continuing development and deployment of tools and procedures required to collect the detector data at high efficiency and develop the calibration, and alignment procedures required in order to understand the detector performance at the level necessary for physics analysis. Support for both participating U.S. national laboratories and CERN will also be provided for technical coordination and program management.

To date, U.S. detector support efforts have focused on hardware commissioning and on the infrastructure needed for full analysis of simulated and cosmic ray data using professional-quality software. Grid computing solutions are integrated into the experiment computing models, building on the tools provided by the Scientific Discovery through Advanced Computing (SciDAC) Open Science Grid project. The grid provides U.S. researchers the access and computing power needed to analyze the large and complex data sets. For FY 2010, computing hardware facilities running grid computing interfaces are essential to enable a rapid development cycle for processing and analyzing the data and improving analysis algorithms in the wake of first collisions and physics-quality data.

Support is also provided for detector R&D, with specific focus on detector technologies needed to accommodate the proposed LHC upgrade in luminosity. Pre-conceptual studies for long-

[a] Report EPP 2010: Elementary Particle Physics in the 21st Century is available at http://www7.nationalacademies.org.\bpa\EPP2010.html.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |

term replacements of major elements of the detectors are ongoing, with proposals expected by the end of 2010. The proposals should cover two planned phases (targeted towards installation in 2014 and 2017) for upgraded LHC luminosity and will emphasize areas where U.S. groups have particular expertise and technical capability.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| • **LHC Upgrades** | **—** | **2,500** | **16,000** |

Fabrication of the Accelerator Project for the Upgrade of the LHC (APUL) is initiated in FY 2010. The project will construct components needed for the planned increase of the luminosity of the LHC by a factor of two to three. The Mission Need (CD-0) was approved October 2008 and conceptual design is underway. The expected scope of the project includes the design and fabrication of magnets, collimators, and beam instrumentation. The intent is to have these components built by BNL, LBNL, Fermilab and SLAC and delivered to CERN for installation in the LHC. The U.S. scope has been coordinated with CERN management and takes advantage of U.S. expertise in the particular technical areas.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **Alternating Gradient Synchrotron (AGS) Support** | **644** | **644** | **644** |

Funding continues for long-term D&D of the AGS facility at BNL, as operations as a HEP user facility were terminated at the end of FY 2002.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **Other Facilities** | **12,380** | **11,341** | **10,277** |

This category includes funding for private institutions, government laboratories, and foundations that participate in high energy physics research, as well as recurring contributions to general program operations activities, such as the federal laboratory consortium, financial auditing, support for internal and external program and project reviews, personnel support under the Intergovernmental Personnel Act, and technical consultation on programmatic issues. This category also includes funding to respond to new opportunities and unexpected changes in facilities operations and support.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **Total, Proton Accelerator-Based Physics** | **371,680** | **402,480** | **442,988** |

## Explanation of Funding Changes

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| **Research** | |
| ▪ **Grants Research** | |
| Funding for the core grant research program provides an approximately 3% increase compared to FY 2009, offset by a $1,000,000 decrease due to the completion of fabrication for the T2K experiment in FY 2009. | +700 |

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| ▪ **National Laboratory Research** | |
| Funding for laboratory-based research increases by about 1.2%, maintaining efforts at FY 2009 levels. | +794 |
| **Total, Research** | **+1,494** |
| **Facilities** | |
| ▪ **Proton Accelerator Complex Operations** | |
| Funding for Proton Accelerator Complex Operations is decreased in FY 2010 due to reduced person-power needs. Standardized running procedures and increased automation allow operation with less person-power. | -4,500 |
| ▪ **Proton Accelerator Complex Support** | |
| Proton Accelerator Complex Support funding decreases overall due to a reduced need for GPP and accelerator infrastructure enhancements. | -2,501 |
| ▪ **Proton Accelerator Facility Projects** | |
| • **Current Facility Projects** | |
| Net funding for Current Facility Projects increases for the ramp up of NO$\nu$A ($+31,234,000) offset by the final year of funding for MINER$\nu$A ($-4,100,000). | +27,134 |
| • **Future Facility Projects R&D** | |
| Funding increases to support pre-conceptual design work on the long-baseline neutrino detector, a lepton number violation experiment and Project X. | +7,862 |
| ▪ **Total, Proton Accelerator Facility Projects** | **+34,996** |
| ▪ **Large Hadron Collider Support** | |
| LHC Support funding increases primarily for the Accelerator Project for the Upgrade of the LHC that will contribute to doubling or tripling of the LHC luminosity. Also, funding for LHC Detector Support maintains a constant level of effort. | +12,083 |
| ▪ **Other Facilities** | |
| Funding decreases for activities pending completion of peer review and/or programmatic decisions. | -1,064 |
| **Total, Facilities** | **+39,014** |
| **Total Funding Change, Proton Accelerator-Based Physics** | **+40,508** |

## Electron Accelerator-Based Physics

## Funding Schedule by Activity

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Electron Accelerator-Based Physics | | | |
| Research | 20,724 | 16,512 | 14,361 |
| Facilities | 36,482 | 14,471 | 12,059 |
| Total, Electron Accelerator-Based Physics | 57,206 | 30,983 | 26,420 |

### Description

The Electron Accelerator-Based Physics subprogram utilizes accelerators with high-intensity and ultra-precise beams to create and investigate matter at its most basic level. Over the last few years, the electron B-factory at SLAC has been leading investigations at the Intensity Frontier, providing precision measurements of different behavior of matter and antimatter observed in the decay products of B-mesons. Physicists consider this asymmetric behavior, called charge-parity (CP) violation, to be vital to understanding the apparent predominance of matter over antimatter, one of the greatest puzzles in comprehending the structure of the universe.

CP violation has been observed in the decays of particles containing strange quarks (K mesons) and most recently in particles containing bottom quarks (B mesons). After the observations of CP violation in B mesons were made early in this decade at the SLAC B-factory and a similar accelerator at the Japanese national laboratory for high energy physics (the High Energy Accelerator Research Organization [KEK] B-factory [KEK-B]), a systematic study of the process has been performed to test the current theoretical explanation of CP violation in the Standard Model. This ongoing study requires both new measurements of CP violation in other B meson decays, as well as measurements of other properties of particles containing bottom or charm quarks.

The B-factory has been decommissioned and is awaiting disassembly, following completion of its scientific program in FY 2008. The BaBar detector will have major components removed in 2009 and the PEP-II collider will be kept in a low maintenance configuration awaiting decisions on the possible reuse of its components at domestic labs (Fermilab and Thomas Jefferson National Accelerator Facility) and abroad. The data, which has been accumulated over the B-factory's nine year operating lifetime, will continue to be analyzed by the B-Factory staff, university groups, and foreign collaborators for a few more years.

### Selected FY 2008 Accomplishment

In FY 2008, the SLAC B-factory delivered 57 $fb^{-1}$ (inverse femtobarns) of data of which the BaBar detector captured 54 $fb^{-1}$. The strategy of the FY 2008 run was modified to accommodate the shortened schedule dictated by budget constraints, and most of the collisions were accumulated at beam energies below the B-meson production threshold, unlike the data-taking strategy of the last few years. The science highlight of this run was the discovery of the ground state of the b-quark/anti-b-quark system. Its mass was measured to a fraction of one percent, and its hyperfine mass spitting, a precision test of quantum chromodynamics (QCD), to 4% accuracy. The entire accumulated B-factory data is being investigated for additional heavy quark states. Lengthy, systematic analyses have begun to determine the consistency of CP violation measurements with the numerous decay processes involving bottom quarks.

## Detailed Justification

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| **Research** | **20,724** | **16,512** | **14,361** |

The research program at the B-factory/BaBar Facility at SLAC is now entering a phase of intense analysis of the 557 $fb^{-1}$ data set that has been accumulated over the nine-year operational life of the facility. The number of physicists involved in this effort is expected to fall to approximately 200 over the course of the year now that the B-Factory has completed taking data. Physicists from approximately 30 universities, three national laboratories (LLNL, LBNL, and SLAC) and seven foreign countries will be actively involved in the final data analysis. The physics issues to be addressed include expanding our understanding of CP violation in many particle decay modes and the investigation of the many heavy quark states predicted by Quantum Chromodynamics.

The research program at other electron accelerator facilities complements the B-factory/BaBar efforts and consists of a group of experimental research activities using the Cornell Electron Storage Ring (CESR) accelerator at Cornell University, the KEK-B electron accelerator facilities in Japan, and recently upgraded electron accelerator facilities in China. A total of four U.S. university groups work at KEK-B, four groups work at the Beijing Electron-Positron Collider (BEPC), and 22 U.S. university groups work at CESR. CESR, operated by the NSF, also completed running in FY 2008. In FY 2010, the work will concentrate on the final analysis of data taken at CESR. Smaller efforts will be devoted to operations of the Belle detector at KEK-B in Japan and the Beijing Spectrometer at BEPC and analysis of the data taken.

| | | | |
|---|---|---|---|
| ▪ **Grants Research** | **9,231** | **7,357** | **6,621** |

Grant-based scientists typically constitute about 50–75% of the personnel needed to create, run, and analyze an experiment, and they usually work in collaboration with other university and laboratory groups. Grant-based research efforts are funded based on peer review and at levels commensurate with the effort needed to carry out the experiments.

In FY 2010, funding continues at a reduced level of effort to complete analysis of physics data from BaBar and the CLEO-c experiment at CESR. Included is a small research program devoted to physics studies of much higher performance, higher intensity B-factory. The Italian government is supporting pre-conceptual R&D aimed at developing a proposal for such a facility. The detailed funding allocations will take into account the quality of research as well as the involvement of university-based research groups in the targeted physics research activities.

| | | | |
|---|---|---|---|
| ▪ **National Laboratory Research** | **11,424** | **9,124** | **7,709** |

The national laboratory research program consists of groups at three laboratories participating in experiments at electron accelerator facilities with a physics program similar to the grant program described above. Electron accelerator research activities concentrate on experiments at the SLAC B-factory. HEP will conduct a comparative peer review of laboratory research groups in this subprogram in 2010.

In FY 2010, laboratory-based research in this subprogram continues at a reduced level of effort to complete data analysis from BaBar and CLEO-c. SLAC will continue to maintain strong participation in the B-factory research program, which will be completing a two-year period of intense analysis of the entire B-factory data set. Research groups at LBNL and LLNL have mostly

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| (dollars in thousands) | | | |

transitioned to other activities. A small research program at Fermilab and SLAC devoted to physics studies of the ILC is also supported.

| | | | |
|---|---|---|---|
| ▪ **University Service Accounts** | **69** | **31** | **31** |

University Service Accounts facilitate the support of university groups working at accelerator facilities by providing funds for these groups to purchase needed supplies and services from the laboratories with minimum time and cost overhead. Currently 12 university groups maintain service accounts at SLAC.

| | | | |
|---|---|---|---|
| **Facilities** | **36,482** | **14,471** | **12,059** |
| ▪ **Electron Accelerator Complex Operations** | **24,632** | **12,091** | **11,179** |

B-factory operations ended in FY 2008 with a significantly shortened physics run due to budget constraints. Faced with a very limited final run for the B-factory, the BaBar collaboration decided to optimize its science output by moving the B-factory energy to a nearby resonance below the B meson production threshold where they had traditionally operated to study CP violation and B meson decays. This strategy has generated a unique data set that can be used for detailed studies of QCD processes, rather than only marginally add to the already large existing data set.

Funding for operations supports the transition of the B-factory accelerator complex to a safe and stable maintenance mode and includes D&D activities. This funding category also supports ongoing BaBar computing operations and data analysis. Starting in FY 2009 all funding for SLAC Linac operations became part of Linac Coherent Light Source (LCLS) commissioning supported by the Basic Energy Sciences (BES) program (see the Facilities section of the BES Scientific User Facilities subprogram).

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| SLAC B-Factory | | | |
| Achieved Operating Hours | 2,359 | — | — |
| Planned Operating hours | 1,300 | — | — |
| Optimal hours (estimated) | 5,850 | — | — |
| Percent of Optimal Hours | 40% | — | — |
| Unscheduled Downtime | 15% | — | — |
| Total Number of Users | 1,000 | 800 | 600 |

| | | | |
|---|---|---|---|
| ▪ **Electron Accelerator Complex Support** | **11,850** | **2,380** | **880** |

Funding is provided for the necessary maintenance and operation of computing capabilities in order to support the timely analysis of the B-factory data.

| | | | |
|---|---|---|---|
| **Total, Electron Accelerator-Based Physics** | **57,206** | **30,983** | **26,420** |

## Explanation of Funding Changes

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| **Research** | |
| Funding for electron accelerator-based experimental research is reduced to a level necessary to complete analysis of physics data from BaBar and CLEO-c. Intensive analysis of the major results from BaBar and CLEO-c data will be completed in 2010. | -2,151 |
| **Facilities** | |
| ▪ **Electron Accelerator Complex Operations** | |
| Funding for B-factory Operations is reduced to support the planned profile for safe dismantling and decommissioning of the BaBar detector and putting PEP II into a minimum maintenance configuration. | -912 |
| ▪ **Electron Accelerator Complex Support** | |
| This category is now focused on providing the computing capabilities needed to finish BaBar data analysis. | -1,500 |
| **Total, Facilities** | **-2,412** |
| **Total Funding Change, Electron Accelerator-Based Physics** | **-4,563** |

## Non-Accelerator Physics

## Funding Schedule by Activity

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Non-Accelerator Physics | | | |
| Grants Research | 20,385 | 20,744 | 21,156 |
| National Laboratory Research | 36,913 | 40,297 | 41,106 |
| Projects | 18,486 | 36,630 | 37,059 |
| Other | — | 3,200 | — |
| Total, Non-Accelerator Physics | 75,784 | 100,871 | 99,321 |

### Description

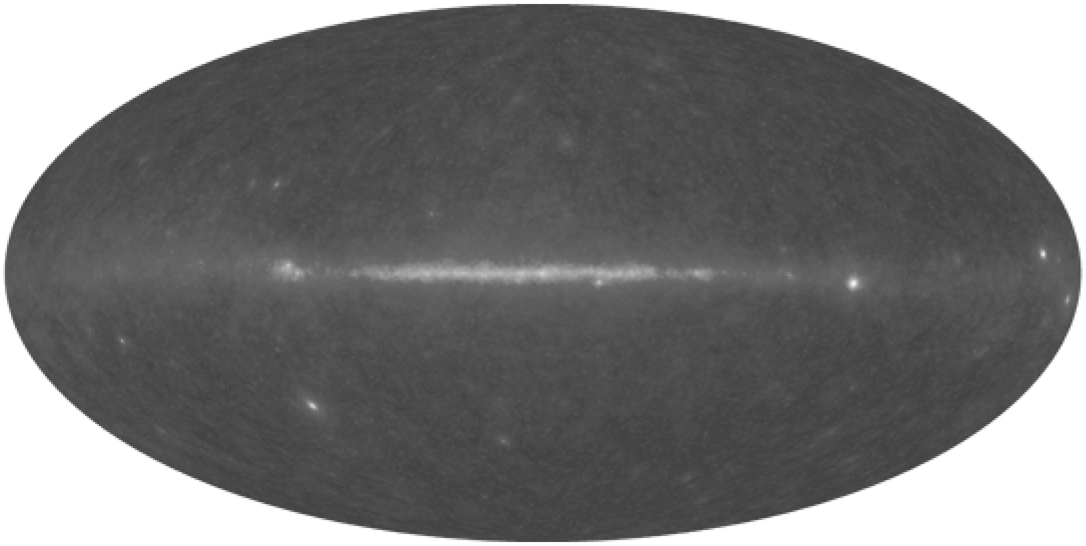
The Non-Accelerator Physics subprogram provides U.S. leadership in the study of those topics in particle physics that cannot be investigated with accelerators or are best studied by other means. Non-Accelerator Physics is playing an increasingly important role in HEP, using ever more sophisticated techniques to probe fundamental physics questions with naturally occurring particles and phenomena. Scientists in this subprogram investigate topics at both the Intensity and Cosmic Frontiers, such as dark matter, dark energy, neutrino properties, proton decay, the highest energy cosmic and gamma rays, and primordial antimatter. These areas of research probe well beyond the Standard Model of particle physics and offer possibilities for discovery of significant new physics.

Some of the non-accelerator particle sources used in this research are cosmic rays and neutrinos from commercial nuclear power reactors, the Sun, and galactic supernovae. Other sources are the light (photons) emitted by supernovae, galaxies and other celestial objects. These experiments utilize particle physics techniques and scientific expertise, as well as the infrastructure of the national laboratories. Experiments are often located at remote sites, such as in deep underground laboratories, on mountain tops, in deserts, or in space.

This subprogram is carried out in collaboration with physicists supported by other government agencies and institutes, among them NSF, NASA, the Naval Research Laboratory (NRL), and the Smithsonian Astrophysical Observatory. Strong interagency coordination and collaboration is one of the hallmarks of this effort. As with the rest of the HEP portfolio, most projects involve international collaboration in all phases of the experiment.

### Selected FY 2008 Accomplishments

- The Large Area Telescope (LAT) launched from Kennedy Space Center in June 2008. This project was a DOE and NASA partnership to build the primary instrument on NASA’s Fermi Gamma-ray Space Telescope (FGST) mission. The international LAT collaboration announced “first light” in August 2008 along with its first all-sky survey which shows the universe as seen in high-energy gamma rays (see the figure below). SLAC led the DOE participation in the fabrication of the LAT and operates the instrument science operations center while data are taken.



Fermi Gamma-ray Space Telescope image of the night sky as seen in high-energy gamma rays

- The Pierre Auger Observatory, located in Argentina, studies the highest energy cosmic rays. It is a collaborative effort between DOE, NSF, and international partners. The American Institute of Physics included results from this facility as one of its top ten physics stories in 2008. Although operations began several years ago with a partial detector array, the full array, covering an area of 3,000 square kilometers, was completed in 2008. Recent results showed a decrease in the number of cosmic rays at the very highest energies, which confirms that there is a physical limit on cosmic ray energies from distant sources.

## Detailed Justification

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| **Grants Research** | **20,385** | **20,744** | **21,156** |

This grant-based program supports research groups at more than 35 universities that perform experiments at non-accelerator-based physics facilities. This program also funds private institutions, government laboratories, and foundations that participate in non-accelerator-based physics research.

Physicists in this research area often work in collaboration with other university and laboratory groups. The selection of research efforts supported is based on peer review. The amount of funding a grant receives takes into account the discovery potential of the proposed research.

In FY 2010, the Non-Accelerator Physics grants program will support research on experiments that finished their fabrication phase in recent years and are now engaged in data collection. These experiments include the Very Energetic Radiation Imaging Telescope Array System (VERITAS), a ground-based gamma ray experiment at the Whipple Observatory in Arizona; the Pierre Auger Observatory discussed above; and the LAT gamma-ray survey on NASA's FGST mission. Other active research efforts include searches for dark matter using the Cryogenic Dark Matter Search (CDMS) at the Soudan Mine in Minnesota and the Axion Dark Matter eXperiment (ADMX) at LLNL. Studies of dark energy use data from the Baryon Oscillation Spectroscopic Survey (BOSS) experiment on the Sloan Digital Sky Survey III (SDSS-III). Research also continues with Super-Kamiokande, a proton decay and neutrino detector located in the Kamioka Underground Laboratory in Japan and the

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |

Enriched Xenon Observatory (EXO), which is searching for neutrino-less double beta decay at the DOE Waste Isolation Pilot Plant facility.

These groups also participate in the research and planning for the Dark Energy Survey (DES) experiment in Chile, the Reactor Neutrino Detector at Daya Bay in China, SuperCDMS at Soudan, the proposed space-based Joint Dark Energy Mission (JDEM), and the proposed ground-based Large Synoptic Survey Telescope (LSST); the latter two will both be used to study dark energy. The DES and Reactor Neutrino experiments are in the fabrication phase and SuperCDMS plans to begin fabrication in 2009. DOE-supported university groups also lead the commissioning and integration for NASA's Alpha Magnetic Spectrometer (AMS) experiment which is on the Space Shuttle manifest for launch in 2010.

HEP also supports research groups participating in the design and R&D efforts for experiments that may be located in NSF's proposed Deep Underground Science and Engineering Laboratory (DUSEL), including next-generation dark matter experiments and a next-generation neutrino-less double beta decay experiment.

| | | | |
|---|---|---|---|
| **National Laboratory Research** | **36,913** | **40,297** | **41,106** |

Groups at several national laboratories participate in non-accelerator-based physics experiments. With strong laboratory technical resources, the laboratory groups provide invaluable and unique service to the research program in terms of experiment management, design, construction, and operations. Laboratory scientists are also involved in the research. The HEP program will conduct a comparative peer-review of the laboratory research efforts in this subprogram in 2010.

In FY 2010, the laboratory research program in non-accelerator physics will continue to support research and operations for ongoing experiments such as the Pierre Auger Observatory, CDMS, the Chicagoland Observatory for Underground Particle Physics 60 kg (COUPP-60) experiment at Fermilab, and ADMX dark matter experiments, the EXO experiment, and the LAT gamma-ray survey on NASA's FGST. SLAC runs the instrument science operations center for the LAT. Laboratory groups also lead the operations and research for various dark energy surveys that use existing telescope facilities.

Laboratory groups participate in the research planning for future experiments in the fabrication phase such as DES, SuperCDMS, and the Reactor Neutrino Detector at Daya Bay. The laboratory program also focuses on the R&D and design efforts for other future projects such as the COUPP-500kg dark matter experiment, other next generation dark matter experiments, and the proposed JDEM and LSST experiments to study dark energy.

| | | | |
|---|---|---|---|
| **Projects** | **18,486** | **36,630** | **37,059** |
| ▪ **Current Projects** | **12,440** | **22,700** | **21,110** |

Fabrication of the Reactor Neutrino Detector will continue in FY 2010. DOE and the Chinese Institute for High Energy Physics are partners for this experiment, which will be located at a site near several commercial nuclear reactors in Daya Bay, China. This experiment will measure and compare the number of neutrinos observed by a detector close to a reactor (the near detector) with the number observed in a far detector. From this data, a crucial neutrino oscillation parameter can be extracted. The U.S. collaboration is led by groups from BNL and LBNL. Construction is expected to be completed in FY 2012.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |

Fabrication of the DES will continue in FY 2010. DOE is supporting the fabrication of a new camera to be installed and operated on the existing Blanco four-meter Telescope at the Cerro Tololo Inter-American Observatory (CTIO) in Chile. The DES project is a partnership between DOE, NSF, which operates the telescope, and international participants. The data management system and upgrades to the telescope facility are supported by NSF. The planned completion for this project is in FY 2011.

Fabrication of the SuperCDMS detector at Soudan will continue in FY 2010. This is an upgrade of an existing dark matter search experiment (CDMS) located in the Soudan Mine to increase sensitivity for direct detection of dark matter over current experiments by a factor of about three. The upgraded detector will have the sensitivity to confirm or rule out many theoretical models of physics beyond the Standard Model involving new supersymmetry particles which may be the source of the dark matter.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **Future Projects R&D** | **6,046** | **13,930** | **15,949** |

This category provides support for R&D and pre-conceptual design activities for promising proposed future experiments. In FY 2010, this includes support for activities involving R&D associated with the DOE and NASA JDEM project as well as support for R&D on technical issues related to the camera (DOE's proposed contribution) for the LSST project. Both NSF and DOE await the priority given to LSST in the National Academies' Decadal Survey for Astronomy and Astrophysics.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **Other** | **—** | **3,200** | **—** |

FY 2009 funding provides for completion of EXO-200 experiment at the Waste Isolation Pilot Plant.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **Total, Non-Accelerator Physics** | **75,784** | **100,871** | **99,321** |

## Explanation of Funding Changes

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| **Grants Research** | |
| Funding for grant-based research continues at approximately a constant level of effort to support experiments that are currently active in commissioning, operations, and/or data analysis. | +412 |
| **National Laboratory Research** | |
| Funding for laboratory-based research is increased, driven by research support for the Reactor Neutrino Detector and LSST. | +809 |

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| **Projects** | |
| ▪ **Current Projects** | |
| Following the project profiles, funding decreases for Reactor Neutrino Detector and DES, offset by an increase for SuperCDMS at Soudan. | -1,590 |
| ▪ **Future Projects R&D** | |
| R&D funding for JDEM, LSST, dark matter, and other astrophysical experiment increases. | +2,019 |
| **Total, Projects** | **+429** |
| **Other** | |
| One-time directed funding in FY 2009 for completion of the EXO-200 experiment at WIPP. | -3,200 |
| **Total Funding Change, Non-Accelerator Physics** | **-1,550** |

## Theoretical Physics

## Funding Schedule by Activity

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Theoretical Physics | | | |
| Grants Research | 24,497 | 25,410 | 25,912 |
| National Laboratory Research | 23,897 | 25,220 | 25,753 |
| Computational HEP | 7,241 | 9,100 | 10,400 |
| Other | 4,397 | 5,074 | 5,175 |
| Total, Theoretical Physics | 60,032 | 64,804 | 67,240 |

### Description

The Theoretical Physics subprogram provides the vision and mathematical framework for understanding and extending the knowledge of particles, forces, space-time, and the universe. This program supports activities that range from detailed calculations of the predictions of the Standard Model to the extrapolation of current knowledge to a new plane of physical phenomena and the identification of the means to experimentally search for them. Symmetries play a major role in the current understanding of the subatomic world: discovering how particle symmetries are realized (or broken) in nature have provided many fundamental breakthroughs in the development of the Standard Model. This subprogram supports and advances research at all three high energy physics Frontiers.

Theoretical physicists play key roles in determining which experiments to perform and in explaining experimental results in terms of underlying theories that describe the interactions of matter, energy, and space-time. The research activities supported by the Theoretical Physics subprogram include, but are not limited to, performing calculations in the quantum field theories of elementary particles that comprise the Standard Model; developing other models for elementary particle processes; interpreting results of measurements in the context of these models; identifying where new physical principles are needed and what their other consequences may be; and constructing and exploiting powerful computational facilities for theoretical calculations of importance for the experimental program.

The Theoretical Physics subprogram supports collaborations between scientists based at different universities and national laboratories. Collaborations with scientists from other federal agencies, such as NSF and NASA, and international partners are supported.

### Selected FY 2008 Accomplishments

- The 2008 Nobel Prize in Physics was shared by Yoichiro Nambu for his theoretical work discovering how symmetry breaking can manifest itself in nature. His work was supported by HEP before he retired from the University of Chicago.
- The processes underlying collisions at particle energies expected to be achieved by the LHC can involve many particles (partons). Calculating such multi-parton scattering probabilities is a challenging task and is important for interpreting LHC data. Various methods have been introduced to compute these amplitudes, some involving techniques derived from string theory. Recently, major advances have been achieved making precision calculations of these probabilities possible.

Calculating quantities relevant to LHC data—such as multi-parton scattering—is an active area of current theoretical work.

- The HEP-supported efforts in the Scientific Discovery through Advanced Computing (SciDAC) program have made significant accomplishments in the past year, including the use of accelerator modeling codes to explain operational instabilities in, and improve the design of, the 12 GeV upgrade of the Continuous Electron Beam Accelerator Facility (CEBAF) at Thomas Jefferson National Accelerator Facility.

## Detailed Justification

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| **Grants Research** | **24,497** | **25,410** | **25,912** |

This program consists of research groups at approximately 70 colleges and universities. It includes funding for private institutions, universities, and foundations that participate in theoretical physics. As part of their research efforts, the university groups train graduate students and postdoctoral researchers. Physicists in this theoretical research area often work in collaboration with other university and laboratory groups. Research efforts are selected based on a peer review process.

The grants program addresses topics across the full range of theoretical physics research. A particularly interesting topic considers additional space-time dimensions that are normally hidden from us. This is motivated by the effort to unify Einstein's theory of gravity with quantum mechanics in a consistent way. Some of these extra dimensions and their consequences may be accessible to experimental investigation and may manifest themselves at the LHC as so-called Kaluza-Klein excitations, named after the physicists who first suggested in the 1920s that we live in a 5-dimensional universe. Another topic of current research interest is the nature of dark matter and dark energy in the context of high energy physics. University research groups are playing leading roles in addressing these research areas.

In FY 2010, the Theoretical Physics grant program is maintained at about a constant level of effort to support the analysis of current and previous experiments, and in the design and optimization of new experiments, so that these experiments can fulfill their maximum potential. It will also support theorists who explore new ideas of physics at the Energy Frontier.

| | | | |
|---|---|---|---|
| **National Laboratory Research** | **23,897** | **25,220** | **25,753** |

The national laboratory theoretical research program consists of groups at six DOE laboratories (Fermilab, SLAC, BNL, ANL, LBNL, and LANL). The laboratory theory groups are a resource for the national research program, with a particular emphasis on collaborations with experimental scientists and data interpretation to provide a clear understanding of the significance of measurements from ongoing experiments and to help shape and develop the laboratories' experimental programs. HEP conducted a comparative peer-review of the laboratory research efforts in this subfield in 2008.

In FY 2010, the laboratory theoretical research groups will address topics across the full range of theoretical physics, including the analysis and interpretation of the new data expected from the Tevatron Collider detectors and forthcoming data from the LHC. There are also efforts to understand properties of neutrinos through reactor, accelerator, and non-accelerator neutrino experiments. As the time of the first beam collisions at the LHC approaches, an increased effort will be made to identify the most promising and sensitive methods for finding signs of new phenomena in the voluminous data that will be produced.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |

It is also possible that certain dark matter particles may be produced at the LHC. Detailed calculations are required to identify effective ways to detect and study their properties.

Funding for the laboratory theory program will be maintained at about a constant level of effort. This is to support laboratory research personnel who participate in the analysis of current and previous experiments so that these experiments can fulfill their potential to make new discoveries and pave the way for the next generation of experiments.

| | | | |
|---|---|---|---|
| **Computational HEP** | **7,241** | **9,100** | **10,400** |

This new budget category includes funding for specific high energy physics research activities that require extensive or customized computational resources. This category includes costs for design, fabrication, procurement, maintenance, and operation of computational hardware that is not associated with specific high energy physics experiments or research facilities. Current activities in this category include the Scientific Discovery through Advanced Computing (SciDAC) program, the Lattice QCD (LQCD) computing initiative, support for dedicated trans-atlantic networking, and U.S. contributions to experiment-independent computer codes required for HEP’s program.

| | | | |
|---|---|---|---|
| ▪ **SciDAC** | **5,243** | **5,600** | **5,600** |

In FY 2010, HEP will continue supporting SciDAC projects and the accelerator simulation solicitation. All SciDAC projects will have mid-term continuation reviews in FY 2009. The SciDAC program is managed and cooperatively funded by the SC program offices, including the Advanced Scientific Computing Research program. There are four principal HEP-supported SciDAC efforts: Type Ia supernova simulations, to better understand the thermonuclear explosions that create supernovae and to generate supernova light curves appropriate for dark energy measurements, a joint effort with Nuclear Physics (NP) and the National Nuclear Security Administration; platform-independent software to facilitate large-scale QCD calculations (see also the LQCD computing initiative below), a joint effort with NP; very large scale, fault-tolerant data handling and distributed grid computing which will allow physicists in the U.S. to analyze petabytes of data produced in Europe at the LHC, a joint effort with NP and the NSF; and large-scale computational infrastructure for accelerator modeling and optimization, to support design and operations of complex accelerator systems throughout the SC complex, a joint effort with NP and the Basic Energy Sciences program.

| | | | |
|---|---|---|---|
| ▪ **Computational QCD and Network Support** | **1,998** | **3,500** | **4,800** |

The understanding of many HEP experimental results has been limited by a lack of precision in QCD calculations which describe the underlying physics; these calculations are in turn limited by a lack of computational power. This activity includes funding for the LQCD computing initiative that is a coordinated effort with the NP program, aimed toward the development, procurement, and operation of a multi-teraflops computer capability for dedicated LQCD simulations. During FY 2009, the first phase of this joint effort will be completed and provide on average about 13 teraflops of capacity. This investment is coordinated with the SciDAC QCD effort described above to ensure that the software codes developed can be run on a variety of available hardware platforms and used by a wide community of researchers. There is a follow-on proposal to deploy approximately 100 teraflops of dedicated capacity for QCD computing, which is currently under review.

In FY 2010, this activity will support the second phase of the LQCD computing initiative, which will provide approximately 100 teraflops of computing capacity. This category also includes funding for

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|

the HEP-related trans-atlantic network requirements between the U.S., CERN, and HEP-related computing facilities in Europe. These requirements are dictated by the unprecedented size of the LHC data set. The dedicated network paths are known as the U.S. LHC Net. In FY 2008, the U.S. LHC Net provided 40 Gigabits per second of connectivity between CERN and points of presence in Chicago and New York. U.S. LHC Net is closely integrated with the DOE Energy Science Network, which does not procure trans-oceanic networking.

| (dollars in thousands) | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **Other** | **4,397** | **5,074** | **5,175** |

This activity includes funding for education and outreach activities, compilations of high energy physics data, reviews of data by the Particle Data Group at LBNL, conferences, studies, workshops, funding for theoretical physics research activities to be determined by peer review, and for responding to new and unexpected physics opportunities. This category also includes $750,000 for the QuarkNet education project in FY 2010. This project takes place in QuarkNet centers which are set up at universities and laboratories around the country. The purpose of each center is to engage high school physics teachers in the analysis of real data from an active high energy physics experiment (such as at the Tevatron Collider or LHC). The experience these teachers garner is taken back to their classrooms in order to expose high school students to the world of high energy physics. The project began in 1999, has been very successful, and will continue through the life of the LHC program.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **Total, Theoretical Physics** | **60,032** | **64,804** | **67,240** |

## Explanation of Funding Changes

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| **Grants Research** | |
| The Theoretical Physics grant program is maintained at about a constant level of effort to support the analysis of current and previous experiments, and in the design and optimization of new experiments. | +502 |
| **National Laboratory Research** | |
| The National Laboratory Research program is maintained at about a constant level of effort to support the analysis of current and previous experiments, and in the design and optimization of new experiments. | +533 |
| **Computational HEP** | |
| Funding for LQCD increases to support the second phase of the computing initiative. | +1,300 |
| **Other** | |
| The increase is primarily due to funding for the Particle Data Group to upgrade their computer systems. | +101 |
| **Total Funding Change, Theoretical Physics** | **+2,436** |

## Advanced Technology R&D

### Funding Schedule by Activity

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Advanced Technology R&D | | | |
| Accelerator Science | 45,076 | 53,224 | 47,324 |
| Accelerator Development | 70,173 | 98,520 | 90,501 |
| Other Technology R&D | 22,894 | 24,456 | 24,701 |
| SBIR/STTR | — | 20,388 | 20,505 |
| Total, Advanced Technology R&D | 138,143 | 196,588 | 183,031 |

### Description

The Advanced Technology R&D subprogram fosters world-leading research in the physics of particle beams, accelerator research and development, and particle detection—all necessary for continued progress in high energy physics. High energy physics research relies on the use of high energy and high intensity particle beams generated with charged particle accelerators, storage rings, and their associated tracking and identification detectors. New developments are stimulated and supported through proposal driven, peer reviewed research. Ultimately, these new technological developments are incorporated into construction projects sponsored by HEP. This subprogram supports and advances research at all three high energy physics Frontiers.

Advanced Technology R&D also provides new technologies and research methods appropriate for a broad range of scientific disciplines, thereby enhancing DOE's broader strategic goals for science. These technologies find applications in synchrotron light sources; intense neutron sources; very short pulse, high-brightness electron beams; and computational software for accelerator and charged particle beam optics design. As a result, the technologies find wide use in nuclear physics, materials science, chemistry, medicine, and industry. Particle accelerators and detectors have migrated into general usage for medical therapy and diagnostics, for preparation of radio-nuclides used in medical treatment facilities, and for the electronics and food industries, to name a few applications. They are also now finding use in defense applications and homeland security.

### Selected FY 2008 Accomplishments

- A collaboration of laboratories, universities, and small businesses has significantly advanced the state of the art for accelerating gradients in normal-conducting accelerating cavities, which is approximately 50 MeV per meter. This effort is directed towards reducing the size and cost of future TeV-scale lepton colliders. At ANL, an intense pulse of electrons was used to excite a microwave field of 100 MeV per meter in a dielectric-loaded accelerating structure. An MIT-designed photonic band-gap accelerating structure also achieved 100 MeV per meter. SLAC has demonstrated 150 MeV per meter in a single-cell, standing-wave copper structure.
- U.S. research groups from national laboratories and universities played a major role in the successful Mercury Intense Target Experiment (MERIT) experiment at CERN, which established the feasibility of using a mercury-jet target for muon production in an intense proton beam. This clears one of the major technical hurdles towards establishing high energy muon colliders.

## Detailed Justification

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| **Accelerator Science** | **45,076** | **53,224** | **47,324** |

This activity focuses on the science underlying the technologies used in particle accelerators and storage rings, as well as the fundamental physics of charged particle beams. National laboratory research efforts are selected based on peer review, laboratory program advisory committees, and special ad hoc review committees. Grant-based research programs are selected based on peer review. Progress is monitored through a system of formal site visits, presentations at appropriate workshops, participation in conferences, and publications.

| | | | |
|---|---|---|---|
| ▪ **Grants Research** | **11,252** | **9,466** | **9,652** |

The FY 2010 budget will continue support for a broad research program in advanced accelerator physics and related technologies. There are 30 accelerator science grants supporting approximately 80 scientists and 45 graduate students. The research program will continue to investigate novel acceleration concepts, such as the use of plasmas and lasers to accelerate charged particles; theoretical studies in advanced beam dynamics, including the study of non-linear optics and space-charge dominated beams; studies of accelerating gradient limits in normal conducting accelerators; development of advanced particle beam sources and instrumentation; and accelerator R&D into the fundamental issues associated with the ionization cooling of muon beams.

| | | | |
|---|---|---|---|
| ▪ **National Laboratory Research** | **33,824** | **35,758** | **37,672** |

This activity supports accelerator R&D efforts and operations of test facilities at ANL, BNL, Fermilab, LBNL and SLAC.

The Accelerator Science program at ANL explores advanced methods to accelerate charged particles with the goal of more efficient, compact, and inexpensive particle accelerators. Efforts in FY 2010 will focus on the development of dielectric wakefield accelerating structures needed to achieve accelerating gradients up to 200 MeV/m. This will be accomplished by upgrading the Argonne Wakefield Accelerator to provide high-charge electron bunches to excite wakefields in the structures.

BNL is the home of the very successful Accelerator Test Facility. The facility supports HEP-funded research at universities as well as through the Small Business Innovation Research (SBIR) program. In FY 2010, the facility will continue a program to test advanced accelerator concepts, develop new instrumentation, and further next-generation, high-brightness electron sources that are based on laser-driven photocathodes.

In FY 2010, LBNL as part of its Laser, Optical Accelerator Systems Integrated Studies (LOASIS) program will conduct research in laser-driven plasma acceleration, with a focus on exploring concepts for cascading GeV wakefield accelerating modules, a promising path to higher gradients and energies. Research and development of muon ionization cooling and theoretical studies of alternative muon acceleration schemes will also be performed.

At Fermilab, the FY 2010 budget will support muon acceleration research, electron beam physics experiments with a high-brightness photo-injector, and beam theory and accelerator simulation

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |

studies performed at the Accelerator Physics Center. R&D in support of the Muon Ionization Cooling Experiment (MICE) at Rutherford Appleton Laboratory, U.K., will also continue.

In FY 2010, SLAC plans to complete fabrication of the Facility for Accelerator Science and Experimental Test Beams (FACET) (supported by Recovery Act funds) and begin preparations for the first round of experiments in which an electron bunch (the beam is not a continuous stream of electrons but structured in discrete bunches) is accelerated by plasma wakefields. Much of the work on advanced accelerator concepts at SLAC is done in collaboration with universities funded by the Accelerator Science activity. The goal of the high gradient effort will be a demonstration of efficient, full-length accelerating structures with gradients above 100 MeV/m.

Also supported in FY 2010 are theoretical studies of space-charge dominated beams at PPPL.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **Projects** | **—** | **8,000** | **—** |

Funding was provided in the FY 2009 Appropriation and in the FY 2009 Recovery Act for the Berkeley Lab Laser Acceleration Project (BELLA). BELLA will further advance the world-leading laser-driven plasma acceleration program, with a focus on exploring concepts for cascading GeV wakefield accelerating modules, a promising path to higher gradients and energies. LOASIS has already accelerated high-quality electron beams to energy exceeding 1 GeV in a one-meter long structure. BELLA will initially improve this by a factor of ten, to 10 GeV.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **Accelerator Development** | **70,173** | **98,520** | **90,501** |

The task of this activity is to demonstrate the feasibility of concepts and technical approaches on an engineering scale. This includes R&D and prototyping to bring new concepts to a stage of engineering readiness where they can be incorporated into existing facilities, upgrade existing facilities, or applied to the design of new facilities. Major thrusts in this activity are superconducting radio frequency (RF) infrastructure development, studies of very high intensity proton sources for potential application in neutrino physics research, and R&D relevant to the proposed International Linear Collider.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **General Accelerator Development** | **46,940** | **39,520** | **33,501** |

This activity focuses on R&D that can be widely applied to a range of accelerator facilities. The work is primarily done at Fermilab, LBNL, SLAC, and BNL. The major areas of R&D are superconducting magnet and related materials technology; high-powered RF acceleration systems; instrumentation; beam dynamics, both linear and nonlinear; and development of large simulation programs.

The R&D program at Fermilab in FY 2010 will address a broad spectrum of technology needs for that facility, including advanced superconducting magnet R&D, R&D for a high-intensity neutrino beam facility, advanced beam instrumentation, and simulation codes to provide improved modeling of all aspects of accelerator operations. Among these topics, emphasis will be placed on developing very high intensity proton sources for neutrino physics research. In particular, funding in this category in FY 2010 decreases as some of these activities move to project-oriented R&D under Proton Accelerator Facility Operations above, and some effort is redirected to other new projects.

The LBNL R&D supported in FY 2010 includes work on very high field superconducting magnets using niobium-tin and similar advanced superconductors, advanced RF systems, laser manipulation and measurement of charged particle beams, and instrumentation development, accelerator theory,

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|

(dollars in thousands)

and computation. The very successful industrially-based program managed by LBNL to develop advanced superconductors, particularly niobium-tin, for the very high field superconducting magnet R&D program will continue to be supported.

The FY 2010 program at SLAC encompasses high-powered RF systems, beam instrumentation, generic electron-positron collider R&D, and advanced beam dynamics and machine simulation code development. Simulation codes for modeling RF system components and high-powered microwave tubes will receive special R&D focus.

The R&D program at BNL includes work on superconducting magnet R&D and associated superconducting magnet materials measurement facility.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **Superconducting RF R&D** | **8,399** | **24,000** | **22,000** |

Superconducting Radio Frequency (SRF) technology is applicable to a variety of future accelerator projects central to the HEP scientific strategy. Centered at Fermilab, the program supports development of the infrastructure necessary for SRF development and includes equipment and facilities for accelerator cavity processing, assembly, and testing and for cryomodule assembly and testing. The infrastructure will be utilized to improve cavity and cryomodule performance and prototype cryomodules for future projects. Information on processing and construction will be of use to a broad spectrum of projects throughout the Office of Science.

In FY 2010, this effort will provide funds for procurement of components and equipment support necessary to develop prototype multi-cavity cryomodules. It also enables continued development of U.S. capabilities for testing individual bare cavities, dressed cavities with all power components attached, and cryomodules. Fermilab is the lead U.S. laboratory and coordinates the national R&D program in this area. FY 2010 funding will also be used to support a fundamental research effort in SRF cavity design that aims to enhance the performance capability, gradient, production yield, reliability, lifetime, and cost of the fundamental RF accelerating structures.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **International Linear Collider R&D** | **14,834** | **35,000** | **35,000** |

A TeV-scale linear collider is widely considered by the international high energy physics community to be the successor to the LHC and essential for advancing scientific progress at the Energy Frontier. In FY 2007, the International Linear Collider (ILC) collaboration under the auspices of the ILC Steering Group and the direction of the Global Design Effort (GDE) completed a detailed review of the R&D to be accomplished worldwide with milestones and priorities for that work. In FY 2008, the GDE initiated a five-year program to develop a Technical Design Report (TDR) that will address outstanding R&D issues, complete a baseline design, and provide a project implementation plan. Completion of the TDR in 2012 is consistent with worldwide resources currently available for the ILC R&D and coincident with first physics from the LHC (necessary to finalize operating parameters for the next linear collider).

In FY 2010, the ILC R&D program will continue to support an important, leading U.S. role in the comprehensive and coordinated international R&D program. Accordingly, efforts will focus on R&D for systems associated with the generation and maintenance of very bright particle beams, such as electron sources, damping rings, beam dynamics development, and beam delivery systems. Support will also be provided for development and prototyping of high level RF equipment and components

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |

associated with the main linac accelerator, including ILC cryomodules. These R&D efforts also have wider applicability to other projects supported by the Office of Science.

| | | | |
|---|---|---|---|
| **Other Technology R&D** | **22,894** | **24,456** | **24,701** |

This category includes R&D on new particle detector technologies. Advanced Detector Research addresses fundamental scientific problems to foster new technologies in particle detection, measurement, and data processing. The Detector Development activity provides funding to national laboratories and universities to bring new particle detection and data processing concepts to engineering readiness so they can be incorporated into existing or new facilities, analogous to the Accelerator Development subprogram.

| | | | |
|---|---|---|---|
| ▪ **Advanced Detector Research** | **709** | **1,737** | **1,769** |

The Advanced Detector Research program provides short-term support for university physicists to develop new detector technologies or advance technologies that have broad applicability to a wide range of high energy physics experiments. Technologies are selected based on anticipated applications that require further technological improvements before deployment. In recent years, three to eight grants a year have been awarded through a competitive peer review program. Final funding levels depend on the number and quality of proposals received.

| | | | |
|---|---|---|---|
| ▪ **Detector Development** | **22,185** | **22,719** | **22,932** |

This activity provides long-term detector development work at the national laboratories and at about 40 universities. The goal is to advance these technologies to a point where there is an opportunity for experiments to successfully adopt the technology. Current areas of investigation include R&D on detector technologies that could be used to pursue new opportunities in future lepton colliders, particle astrophysics, neutrino physics, and experiments that require underground facilities, such as dark matter detection.

The FY 2010 request will maintain R&D efforts directed toward developing new detectors, including prototyping and in-beam studies. A diverse program will be continued, including efforts on particle flow calorimeters, very low-mass trackers, liquid noble gas detectors, transducer technology (e.g., advanced charged-coupled devices, silicon photomultipliers), large area photodetectors, picosecond timing techniques, and radiation resistant, fast readout electronics. Prototype calorimeter tracking and muon detection systems will be studied in the Fermilab test beam, providing a major test of particle flow algorithms and detector construction techniques.

| | | | |
|---|---|---|---|
| **SBIR/STTR** | **—** | **20,388** | **20,505** |

In FY 2008, $16,505,000 and $1,981,000 was transferred to the congressionally mandated Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs, respectively. The FY 2009 and FY 2010 amounts are estimated requirements for the continuation of these programs.

| | | | |
|---|---|---|---|
| **Total, Advanced Technology R&D** | **138,143** | **196,588** | **183,031** |

## Explanation of Funding Changes

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| **Accelerator Science** | |
| ▪ **Grants Research** | |
| Funding for grant-based research maintains efforts at FY 2009 levels. | +186 |
| ▪ **National Laboratory Research** | |
| Funding for the base research program at the laboratories is about the same as FY 2009, after one-time investments ($3,000,000) in FY 2009 in infrastructure and the commissioning costs ($+5,100,000) for FACET in FY 2010 are taken into account. | +1,914 |
| ▪ **Projects** | |
| Project funding for BELLA is completed in FY 2009. | -8,000 |
| **Total, Accelerator Science** | **-5,900** |
| **Accelerator Development** | |
| ▪ **General Accelerator Development** | |
| Funding for General Accelerator Development activities decreases because work on conceptual design for a long-baseline neutrino beam has been reassigned to Proton Accelerator facility operations, and some effort is redirected to R&D on other new proton accelerator facility projects. | -6,019 |
| ▪ **Superconducting RF R&D** | |
| Planned funding for Superconducting RF development is reduced since additional funds are provided from the FY 2009 Recovery Act. | -2,000 |
| **Total, Accelerator Development** | **-8,019** |
| **Other Technology R&D** | |
| Funding for Other Technology R&D is approximately the same as FY 2009. | +245 |
| **SBIR/STTR** | |
| SBIR/STTR programs are funded at the mandated level. | +117 |
| **Total Funding Change, Advanced Technology R&D** | **-13,557** |

## Supporting Information

### Operating Expenses, Capital Equipment and Construction Summary

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Operating Expenses | 642,398 | 713,308 | 723,546 |
| Capital Equipment | 46,579 | 74,961 | 91,082 |
| General Plant Projects | 9,568 | 4,417 | 2,952 |
| Accelerator Improvement Projects | 4,300 | 3,040 | 1,420 |
| Total, High Energy Physics | 702,845 | 795,726 | 819,000 |

### Funding Summary

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Research | | | |
| National Laboratories | 279,152 | 320,675 | 313,195 |
| Universities | 121,101 | 127,633 | 130,000 |
| Other | 2,264 | 3,913 | 6,371 |
| Total, Research | 402,517 | 452,221 | 449,566 |
| Scientific User Facilities Operations | 253,072 | 244,066 | 241,098 |
| Major Items of Equipment | 34,232 | 67,066 | 96,910 |
| Other | 13,024 | 32,373 | 31,426 |
| Total, High Energy Physics | 702,845 | 795,726 | 819,000 |

### Scientific User Facilities Operations

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Tevatron | 151,018 | 157,658 | 158,519 |
| B-factory | 36,482 | 14,471 | 12,059 |
| LHC Detector Support and Operations | 65,572 | 71,937 | 70,520 |
| Total, Scientific User Facilities Operations | 253,072 | 244,066 | 241,098 |

## Total Facility Hours and Users

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| Proton Accelerator Complex[a] | | | |
| Achieved Operating Hours | 6,500 | N/A | N/A |
| Planned Operating Hours | 5,040 | 5,040 | 5,400 |
| Optimal hours (estimated) | 5,400 | 5,400 | 5,400 |
| Percent of Optimal Hours | 120% | 93% | 100% |
| Unscheduled Downtime | 16% | N/A | N/A |
| Total Number of Users | 2,160 | 2,160 | 2,000 |
| SLAC B-factory | | | |
| Achieved Operating Hours | 2,359 | — | — |
| Planned Operating hours | 1,300 | — | — |
| Optimal hours (estimated) | 5,850 | — | — |
| Percent of Optimal Hours | 40% | — | — |
| Unscheduled Downtime | 15% | — | — |
| Total Number of Users | 1,000 | 800 | 600 |
| Total Facilities | | | |
| Achieved Operating Hours | 8,859 | N/A | N/A |
| Planned Operating hours | 6,340 | 5,040 | 5,400 |
| Optimal hours (estimated) | 11,250 | 5,400 | 5,400 |
| Percent of Optimal Hours | 78% | 93% | 100% |
| Unscheduled Downtime | 15% | N/A | N/A |
| Total Number of Users | 3,160 | 2,960 | 2,600 |

[a] Tevatron and NuMI operations run in parallel.

## Major Items of Equipment (MIE)

(dollars in thousands)

| | Prior Years | FY 2008 | FY 2009 | FY 2009 Additional Approp. | FY 2010 | Out-Years | Total |
|---|---|---|---|---|---|---|---|
| **Proton Accelerator-Based Physics** | | | | | | | |
| MINERνA | | | | | | | |
| Total Estimated Costs (TEC) | — | 5,000 | 4,900 | — | 800 | — | 10,700 |
| Other Project Costs (OPC) | 3,950 | 2,150 | — | — | — | — | 6,100 |
| Total Project Costs (TPC) | 3,950 | 7,150 | 4,900 | — | 800 | — | 16,800 |
| NOνA | | | | | | | |
| TEC | 1,000 | — | 15,106 | 14,936 | 59,000 | 107,340 | 197,382 |
| OPC | 15,860 | 12,034 | 12,660 | 40,064 | — | — | 80,618 |
| TPC | 16,860 | 12,034 | 27,766 | 55,000 | 59,000 | 107,340 | 278,000 |
| T2K | | | | | | | |
| TEC | — | 1,848 | 1,000 | — | — | — | 2,848 |
| OPC | 1,200 | 660 | — | — | — | — | 1,860 |
| TPC | 1,200 | 2,508 | 1,000 | — | — | — | 4,708 |
| Accelerator Project for the Upgrade of the LHC | | | | | | | |
| TEC | — | — | — | — | TBD[a] | TBD | TBD |
| OPC | — | — | 2,500 | — | 16,000[a] | TBD | TBD |
| TPC | — | — | 2,500 | — | 16,000 | 6,500–8,500 | 25,000–27,000 |
| **Non-Accelerator Physics** | | | | | | | |
| Reactor Neutrino Detector | | | | | | | |
| TEC | 500 | 4,960 | 13,000 | — | 10,780 | 1,960 | 31,200 |
| OPC | 500 | 1,980 | — | — | 220 | 100 | 2,800 |
| TPC | 1,000 | 6,940 | 13,000 | — | 11,000 | 2,060 | 34,000 |

[a] This MIE is not yet baselined, and therefore the TEC and OPC have not been determined. Mission Need (CD-0) was approved on November 20, 2008, with an estimated cost range of $25,000,000–$27,000,000. The FY 2010 Budget Request is for engineering design only. Engineering design may include limited fabrication and testing of design concepts. Fund for full fabrication will be requested after approval of the Performance Baseline, CD-2.

(dollars in thousands)

| | Prior Years | FY 2008 | FY 2009 | FY 2009 Additional Approp. | FY 2010 | Out-Years | Total |
|---|---|---|---|---|---|---|---|
| Dark Energy Survey | | | | | | | |
| TEC | — | 1,650 | 7,990 | — | 8,410 | 5,000 | 23,050 |
| OPC | 7,040 | 3,950 | 910 | — | 200 | — | 12,100 |
| TPC | 7,040 | 5,600 | 8,900 | — | 8,610 | 5,000 | 35,150 |
| SuperCDMS at Soudan[a] | | | | | | | |
| TEC/TPC | — | — | 1,000 | — | 1,500 | — | 2,500 |
| **Advanced Technology R&D** | | | | | | | |
| Advanced Accelerator R&D Test Facility[b] | | | | | | | |
| BELLA | | | | | | | |
| TEC | — | — | 8,000 | 18,718 | — | — | 26,718 |
| OPC | — | — | — | 2,000 | — | — | 2,000 |
| TPC | — | — | 8,000 | 20,718 | — | — | 28,718 |
| FACET | | | | | | | |
| TEC | — | — | — | 11,000 | — | — | 11,000 |
| OPC | — | — | — | 2,000 | — | — | 2,000 |
| TPC | — | — | — | 13,000 | — | — | 13,000 |
| Total MIEs | | | | | | | |
| TEC | | 13,458 | 50,996 | 44,654 | 80,490 | | |
| OPC | | 20,774 | 16,070 | 44,064 | 16,420 | | |
| TPC | | 34,232 | 67,066 | 88,718 | 96,910 | | |

[a] This MIE appeared as CDMS-25 in the FY 2009 budget request. See the text for details of the changes. Mission Need (CD-0) was approved on September 28, 2007, with an estimated cost range of $6,000,000–$7,000,000. Funds for full fabrication will be requested after approval of the project baseline.

[b] Two proposals, Berkeley Lab Laser Acceleration (BELLA) Project and the Facility for Accelerator Science and Experimental Test Beams (FACET) were reviewed as candidates for this facility. Both received excellent reviews and using Recovery Act funds, it will be possible to do both. FACET will receive only Recovery Act funds and BELLA will receive both FY 2009 funds and Recovery Act funds. Neither project is baselined yet, so the split between TEC and OPC funds is not yet determined. Mission Need (CD-0) was approved on February 27, 2008 with an estimated cost range of $32,000,000–$37,000,000 for both projects. This early estimate did not explicitly include OPC costs. Funds for full fabrication will be requested after approval of the Performance Baseline, CD-2.

**Proton Accelerator-Based Physics MIEs:**

*Main Injector Experiment ν-A (MINERνA)* will make precision measurements of neutrino interaction rates in the NuMI beam, an important input to analyze data from neutrino oscillation experiments (such as MINOS and NOνA). The planned completion for this project is in FY 2010.

*NuMI Off-axis Neutrino Appearance (NOνA) Detector* will use the NuMI beam from Fermilab to directly observe and measure the transformation of muon neutrinos into electron neutrinos over a distance of 700 km. The project also includes improvements to the proton source to increase the intensity of the NuMI beam. The occurrence of these particular neutrino "flavor" changes is expected to be much rarer than the phenomenon under study with MINOS. The baseline was approved in September 2008 with a TPC of $278,000,000. This is $8,000,000 more than that documented in the FY 2009 request. The project was delayed for approximately one year due to zero funding in the FY 2008 Omnibus appropriation, when the work was rescheduled for later completion, the Total Project Cost increased due to escalation. The planned completion for this project is in 2014.

*Tokai-to-Kamioka (T2K) Near Detector* is a new accelerator-based neutrino oscillation experiment in Japan. This experiment utilizes neutrino beams from the Japanese proton accelerator facility, measured both in a nearby detector and in the Super-Kamiokande detector approximately 300 km away, to study neutrino oscillations in a manner complementary to NOνA. The planned completion for this project is in FY 2009.

*Accelerator Project for the Upgrade of the LHC (APUL)* is a new MIE planned to begin fabrication in FY 2010. The scope of the project is to design and construct selected magnets, power systems, and beam instrumentation needed for increasing the LHC luminosity by a factor of two to three. The Mission Need was approved October 2008 and conceptual design is underway, funded under Other Project Costs. Brookhaven National Laboratory and Fermilab are expected to fabricate components and deliver them to CERN for installation in the LHC.

**Non-Accelerator Physics MIEs:**

*Reactor Neutrino Detector*, located in Daya Bay, China, is being fabricated in partnership with research institutes in China. This experiment will use anti-neutrinos produced by commercial power reactors to precisely measure a fundamental parameter that will help resolve ambiguities in neutrino properties and will be input to setting future directions of neutrino research. The planned completion for this project is in FY 2012.

*Dark Energy Survey (DES) project* will provide the next step beyond the discovery of dark energy by making more detailed studies using several different observational methods. DOE is supporting the fabrication of a new camera to be installed and operated on the existing Blanco four-meter Telescope at the Cerro Tololo Inter-American Observatory (CTIO) in Chile. This project is a partnership between DOE and the NSF, which operates the telescope, along with international participation. The planned completion of this project is in FY 2011.

*Super Cryogenic Dark Matter Survey (SuperCDMS) at Soudan* is an upgrade of an existing dark matter search experiment (CDMS) to increase sensitivity for direct detection of dark matter over current experiments by a factor of three. The ultra-cold, supersensitive superconducting germanium detectors will be manufactured at Stanford University and tested at various U.S. institutions before being installed at the Soudan Underground Laboratory in Minnesota. This project has been reduced in size compared to the FY 2009 budget request in order to complete the experiment more quickly and maintain scientific competitiveness with other dark matter detection technologies.

**Advanced Technology R&D MIEs:**

*Advanced Accelerator R&D Test Facility* was initiated in FY 2009. Two proposals, Berkeley Lab Laser Acceleration (BELLA) Project at LBNL and the Facility for Accelerator Science and Experimental Test Beams (FACET) at SLAC were reviewed as candidates for this facility. Both received excellent reviews and using Recovery Act funds, it will be possible to do both. FACET will receive only Recovery Act funds and BELLA will receive both FY 2009 funds and Recovery Act funds. FACET will fabricate equipment to be installed in the portion of the SLAC linac not utilized by Linac Coherent Light Source. It will support experiments on plasma wakefield acceleration of electrons, a technique that exploits the field created by one electron bunch moving through a plasma to accelerate a second bunch following in the wake of the first. The BELLA Project will utilize a 1 petawatt laser to produce the wakefields in the plasma, instead of a beam of electrons. The goal of the project is to produce 10 GeV electron beams in less than 1 meter of plasma.

## Scientific Employment

| | FY 2008 actual | FY 2009 estimate | FY 2010 estimate |
|---|---|---|---|
| # University Grants | 200 | 200 | 200 |
| # Laboratory Groups | 47 | 45 | 45 |
| # Permanent Ph.D.’s (FTEs) | 1,135 | 1,135 | 1,140 |
| # Postdoctoral Associates (FTEs) | 525 | 550 | 550 |
| # Graduate Students (FTEs) | 585 | 595 | 595 |
| # Ph.D.’s awarded | 110 | 110 | 110 |

# Nuclear Physics

## Funding Profile by Subprogram

(dollars in thousands)

| | FY 2008 Current Appropriation | FY 2009 Original Appropriation | FY 2009 Additional Appropriation[a] | FY 2010 Request |
|---|---|---|---|---|
| Nuclear Physics | | | | |
| Medium Energy Nuclear Physics | 107,206 | 121,752 | +19,700 | 131,009 |
| Heavy Ion Nuclear Physics | 182,236 | 200,373 | +16,235 | 219,556 |
| Low Energy Nuclear Physics | 82,279 | 94,618 | +24,545 | 116,816 |
| Nuclear Theory | 34,411 | 39,376 | +14,108 | 43,419 |
| Isotope Development and Production for Research and Applications [b] | — | 24,900 | +15,212 | 19,200 |
| Subtotal, Nuclear Physics | 406,132 | 481,019 | +89,800 | 530,000 |
| Construction | 17,539 | 31,061 | +65,000 | 22,000 |
| Total, Nuclear Physics | 423,671[cd] | 512,080 | +154,800 | 552,000 |

**Public Law Authorizations:**

Public Law 95–91, "Department of Energy Organization Act", 1977

Public Law 101–101, "1989 Energy and Water Development Appropriations Act" (Established the Isotope Production and Distribution Program Fund)

Public Law 103–316, "1995 Energy and Water Development Appropriations Act" (Amendment to the Isotope Production and Distribution Program Fund to provide flexibility in pricing without regard to full-cost recovery)

Public Law 109–58, "Energy Policy Act of 2005"

Public Law 110–69, "America COMPETES Act of 2007"

## Program Overview

### Mission

The mission of the Nuclear Physics (NP) program is to discover, explore, and understand all forms of nuclear matter. The fundamental particles that compose nuclear matter—quarks and gluons—are relatively well understood, but exactly how they fit together and interact to create different types of matter in the universe is still largely not understood. To solve this mystery, NP supports experimental and theoretical research—along with the development and operation of particle accelerators and advanced technologies—to create, detect, and describe the different forms and complexities of nuclear matter that can exist in the universe, including those that are no longer found naturally.

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[a] The Additional Appropriation column reflects the planned allocation of funding from the American Recovery and Reinvestment Act of 2009, P.L. 111–5. See the Department of Energy website at http://www.energy.gov/recovery for up-to-date information regarding Recovery Act funding

[b] The Isotope Development and Production for Research and Applications program is transferred to the Office of Science from the Office of Nuclear Energy in FY 2009.

[c] Includes $1,500,000 provided by the Supplemental Appropriations Act, 2008, P.L. 110–252.

[d] Total is reduced by $10,555,000: $9,425,000 of which was transferred to the Small Business Innovative Research (SBIR) program and $1,130,000 of which was transferred to the Small Business Technology Transfer (STTR) program.

**Background**

It is one of the enduring mysteries of the universe: What, really, is matter? What are the units that matter is made of, and how do they fit together to give matter the properties we observe? These are questions which philosophers have wrestled with for millennia. Twenty-four hundred years ago, the Greek philosopher Democritus suggested that if one were to divide matter into smaller and smaller pieces, one would eventually be left with indivisible entities called atoma. It was not until the 1800s, however, that scientists had solid evidence that such atoma—or atoms—actually existed, and it was not until the early 1900s that techniques were developed that made it possible to examine their composition.

In 1909 the physicist Ernest Rutherford fired a beam of helium ions at a thin sheet of gold foil and measured how the ions scattered, showing that each atom has at its center a small, dense, positively charged core, which Rutherford named the nucleus. Scientists later determined that the nucleus is surrounded by a cloud of tiny negatively charged electrons that account for less than 0.1% of the total mass of the atom. Upon closer inspection, researchers found that the nucleus was composed of even smaller particles: the positively charged proton and the electrically neutral neutron. Research showed that protons and neutrons are bound in the nucleus by a fundamental force named the strong force because it is far stronger than either gravity or electromagnetism, although it operates on smaller distance scales. As scientists delved further into the properties of the proton and neutron, they discovered that each proton and neutron is composed of three tiny particles called quarks. Quarks are bound together by yet other particles called gluons, which are believed to be the generators of the strong force. One of the major goals of nuclear physics is to understand precisely how quarks and gluons bind together to create protons, neutrons, and other hadrons (the generic name for particles composed of quarks) and, in turn, to determine how all hadrons fit together to create nuclei and other types of matter.

The quest to understand matter takes place through both theory and experiment, with both being necessary to develop a full understanding of the properties and behavior of matter. In the theoretical approach, scientists have developed a precise mathematical description of how the quarks and gluons in nuclear matter interact, referred to as Quantum Chromodynamics (QCD). On the experimental side, scientists accumulate a great deal of experimental data about the behavior of quarks and gluons as well as protons, neutrons, and nuclei in a variety of settings. Unlike Rutherford's table-top experiment, most of the experiments today require large facilities spanning acres. These particle accelerators slam bits of matter into each other, and scientists observe the results. The main differences from Rutherford's time are the ability to accelerate the bits of matter to much higher speeds, the variety of types of matter that can be used, and the sophistication of the instruments used in the observations. The careful integration and comparison of experimental measurements with theoretical calculations provides both insight into the behavior of matter and the information needed to test the validity of theoretical models.

Nuclear physics seeks to understand matter in all of its manifestations—not just the familiar forms of matter we see around us, but also such exotic forms as the matter that existed in the first moments after the creation of the universe and the matter that exists today inside neutron stars—and to understand why matter takes on the particular forms that it does. Nuclear physics has come to focus on three broad yet tightly interrelated areas of inquiry. These three areas are described in *The Frontiers of Nuclear Science*[a], a long range plan for nuclear science released in 2007 by the Nuclear Science Advisory Committee (NSAC). The plan represents a consensus within the nuclear science community about compelling scientific thrusts. The three frontiers the long range plan identified are:

[a] http://www.sc.doe.gov/np/nsac/nsac.html

- **Quantum Chromodynamics:** The focus of this frontier is to develop a complete understanding of how quarks and gluons assemble themselves into the various forms of matter and, as part of that process, to search for yet undiscovered forms of matter. While nuclear scientists want to know how quarks and gluons assemble to form matter, they also want to understand what happens when nucleons "melt." QCD predicts that nuclear matter can change its state in somewhat the same way that ordinary matter can change from solid to liquid to gas. This can happen when nucleons are compressed well beyond the density of atomic nuclei, as in the core of a neutron star, or when they are heated to the kind of extreme temperatures found in the early universe. One of the most startling recent discoveries is the creation of a new form of matter, thought to have existed in only moments after the birth of the universe under conditions of extreme temperature and density, and the fact that it behaves as an almost perfect liquid instead of a dilute gaseous plasma as originally hypothesized.
- **Nuclei and Nuclear Astrophysics:** Nuclear physicists seek to understand how protons and neutrons combine to form atomic nuclei and how these nuclei have arisen during the 13.7 billion years since the birth of the cosmos. The forces that bind protons and neutrons together into nuclei are immensely strong, with the result that nuclear processes such as nuclear fusion and fission can release huge amounts of energy. Looking inward, nuclear scientists seek a comprehensive description of the behavioral characteristics of multi-nucleon systems and marginally stable exotic nuclei not naturally found on earth. Looking outward, nuclear scientists seek to understand the nuclear processes that have shaped the cosmos, from the origin of the elements, the evolution of stars, and the detonation of supernovae, to the structure of neutron stars and the nature of matter at extreme densities. Nuclear scientists have taken great strides in nuclear astrophysics, for example by decreasing the limits of the age of the universe by about one billion years through studies of the reaction cross sections that control hydrogen burning in stars.
- **Fundamental Symmetries and Neutrinos:** Although the strong force plays the dominant role in the nucleus, it is not the only force that nuclear physicists must consider. Because protons (and quarks) are electrically charged, electromagnetism comes into play in such circumstances as proton-proton interactions, and the weak force is responsible for the transformation of protons into neutrons and vice versa. The three forces have been unified into a single theory, referred to as the Standard Model, which does an excellent job of explaining the interactions of the various fundamental particles. However, certain inadequacies of that theory have led physicists to begin developing a New Standard Model. In particular, nuclear physicists are interested in developing a better understanding of the fundamental properties of the neutron and of the neutrino, the nearly undetectable fundamental particle produced by the weak interaction that was first indirectly detected in nuclear beta decay. One of the most surprising results to come out of neutrino studies in the past many years was the discovery that electron neutrinos produced in the Sun are changing into a different type of neutrino, thus explaining the puzzling shortage of events seen in previous solar neutrino detectors and confirming models for solar energy production.

For over 50 years, this program and its predecessors have been at the forefront of the development and production of stable and radioactive isotope products that are now used worldwide. DOE applies its unique expertise and capabilities to address technology issues associated with the application, production, handling, and use of isotopes. Adequate supplies of medical and research isotopes are essential to maintain effective diagnosis, treatment, and research capabilities in the U.S. The program's products and services are sold to over 20 countries. The program produces isotopes only where there is no U.S. private sector capability or other production capacity is insufficient to meet U.S. needs.

## Strategic and GPRA Unit Program Goals

The NP program has one Government Performance and Results Act (GPRA) Unit Program Goal which contributes to Strategic Goals 3.1 and 3.2 in the "goal cascade."

- GPRA Unit Program Goal 3.1/2.47.00—Explore Nuclear Matter—from Quarks to Stars—Understand the evolution and structure of nuclear matter, from the smallest building blocks, quarks and gluons, to the stable elements in the Universe created by stars; to unique isotopes created in the laboratory that exist at the limits of stability and possess radically different properties from known matter.

## Contribution to GPRA Unit Program Goal 3.1/2.47.00, Explore Nuclear Matter - from Quarks to Stars

The NP subprograms (Medium Energy, Heavy Ion, Low Energy, Nuclear Theory, and Isotope Development and Production for Research and Applications) contribute to this goal by supporting innovative, peer-reviewed scientific research to advance knowledge and provide insights into the nature of energy and matter, and in particular, to investigate the fundamental forces that hold the nucleus of the atom together, and determine the detailed structure and behavior of atomic nuclei. NP contributes by building and supporting world-leading scientific facilities and state-of-the-art instruments necessary to carry out its basic research agenda. Scientific discoveries at the frontiers of nuclear physics further the Nation's energy-related research capacity, which in turn, provides for the Nation's security, economic growth and opportunities, and improved quality of life. The Isotope subprogram provides facilities and capabilities for the production of research and commercial stable and radioactive isotopes, scientific and technical staff associated with general isotope research and production, and a supply of critical isotopes to address the needs of the Nation.

The following indicators establish specific long-term goals in Scientific Discovery that NP is committed to, and progress can be measured against:

- Making precision measurements of fundamental properties of the proton, neutron, and simple nuclei for comparison with theoretical calculations to provide a quantitative understanding of their quark substructure;
- Searching for and characterizing the properties of the quark-gluon plasma by briefly recreating tiny samples of hot, dense nuclear matter;
- Investigating new regions of nuclear structure, studying interactions in nuclear matter like those occurring in neutron stars, and determining the reactions that created the nuclei of the chemical elements inside stars and supernovae; and
- Determining the fundamental properties of neutrinos and fundamental symmetries by using neutrinos from the sun and nuclear reactors and by using radioactive decay measurements.

## Annual Performance Results and Targets

| FY 2005 Results | FY 2006 Results | FY 2007 Results | FY 2008 Results | FY 2009 Targets | FY 2010 Targets |
|---|---|---|---|---|---|
| GPRA Unit Program Goal 3.1/2.47.00 – Explore Nuclear Matter, from Quarks to the Stars | | | | | |
| Maintained and operated Nuclear Physics scientific user facilities so the unscheduled operational downtime was 13%, on average, of total scheduled operating time. [Met Goal] | Maintained and operated Nuclear Physics scientific user facilities so the unscheduled operational downtime was 6%, on average, of total scheduled operating time. [Met Goal] | Maintained and operated Nuclear Physics scientific user facilities so the unscheduled operational downtime was 10.4%, on average, of total scheduled operating time. [Met Goal] | Achieve at least 80% average operation time of the scientific user facilities as a percentage of the total scheduled annual operating time. [Met Goal] | Achieve at least 80% average operation time of the scientific user facilities as a percentage of the total scheduled annual operating time. | Achieve at least 80% average operation time of the scientific user facilities as a percentage of the total scheduled annual operating time. |
| | | | Achieve within 10% for both the cost-weighted mean percentage variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects. [Met Goal] | Achieve within 10% for both the cost-weighted mean percentage variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects. | Achieve within 10% for both the cost-weighted mean percentage variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects. |
| Medium Energy Nuclear Physics | | | | | |
| Weighted average number (within 20% of baseline estimate) of billions of events recorded by experiments in Hall A (2.83), Hall B (8.06), and Hall C (2.11), respectively, at the Continuous Electron Beam Accelerator Facility. [Met Goal] | Weighted average number (within 20% of baseline estimate) of billions of events recorded by experiments in Hall A (1.77), Hall B (9.9), and Hall C (1.9), respectively, at the Continuous Electron Beam Accelerator Facility. [Met Goal] | Weighted average number (within 20% of baseline estimate) of billions of events recorded by experiments in Hall A (2.49), Hall B (12.42), and Hall C (3.01) at the Continuous Electron Beam Accelerator Facility. [Met Goal] | Weighted average number (within 20% of baseline estimate) of billions of events recorded by experiments in Hall A, Hall B, and Hall C at the Continuous Electron Beam Accelerator Facility. FY 2008 Baseline: Hall A: 4.0; Hall B: 20.0; and Hall C: 5.0. [Met Goal] | Achieve at least 80% of the integrated delivered beam used effectively for experimental research in each of Halls A, B and C at the Continuous Electron Beam Accelerator Facility measured as a percentage of the scheduled delivered beam considered effective for each Hall. | Achieve at least 80% of the integrated delivered beam used effectively for experimental research in each of Halls A, B and C at the Continuous Electron Beam Accelerator Facility measured as a percentage of the scheduled delivered beam considered effective for each Hall. |
| | | | | Achieve at least 80% of the projected integrated proton-proton collision luminosity sampled by each of the PHENIX and STAR experiments at the Relativistic Heavy Ion Collider, where the projected values take into account anticipated collider performance and detector data-taking efficiencies. | Achieve at least 80% of the projected integrated proton-proton collision luminosity sampled by each of the PHENIX and STAR experiments at the Relativistic Heavy Ion Collider, where the projected values take into account anticipated collider performance and detector data-taking efficiencies. |

| FY 2005 Results | FY 2006 Results | FY 2007 Results | FY 2008 Results | FY 2009 Targets | FY 2010 Targets |
|---|---|---|---|---|---|
| Heavy Ion Nuclear Physics | | | | | |
| Weighted average number (within 30% of baseline estimate) of millions of events sampled by the PHENIX (900) and recorded by the STAR (40) detectors, respectively, at the Relativistic Heavy Ion Collider. [Met Goal] | No Target. (The Relativistic Heavy Ion Collider did not operate in heavy ion mode during FY 2006) | Weighted average number (within 30% of baseline estimate) of millions of events sampled by PHENIX (5,100) and recorded by the STAR (86.6) detectors during the heavy ion run at the Relativistic Heavy Ion Collider. [Met Goal] | Weighted average number (within 30% of baseline estimate) of millions of heavy-ion collision events sampled by the PHENIX and recorded by the STAR detectors, respectively, at the Relativistic Heavy Ion Collider. FY 2008 Baseline: PHENIX sample=7,500; STAR recorded=60. [Met Goal] | No target. RHIC is not running heavy ion collisions in FY 2009. | Achieve at least 80% of the projected equivalent integrated proton-proton collision luminosity sampled by each of the PHENIX and STAR experiments at the Relativistic Heavy Ion Collider, where the projected values take into account anticipated collider performance and detector data-taking efficiencies. |
| Low Energy Nuclear Physics | | | | | |
| Weighted average number (within 20% of baseline estimate) of billions of events recorded by experiments at the Argonne Tandem Linac Accelerator System (28.1) and Holifield Radioactive Ion Beam (3.76) facilities, respectively. [Met Goal] | Weighted average number (within 20% of baseline estimate) of billions of events recorded by experiments at the Argonne Tandem Linac Accelerator System (24.6) and Holifield Radioactive Ion Beam (7.1) facilities. [Met Goal] | Weighted average number (within 20% of baseline estimate) of billions of events recorded by experiments at the Argonne Tandem Linac Accelerator System (27.6) and Holifield Radioactive Ion Beam (7.1) facilities. [Met Goal] | Weighted average number (within 20% of baseline estimate) of billions of events recorded by experiments at the Argonne Tandem Linac Accelerator System and Holifield Radioactive Ion Beam facilities, respectively. FY 2008 Baseline: ATLAS-22; HRIBF-2.4. [Met Goal] | Achieve at least 80% of the integrated delivered beam used effectively for all experiments run at each of the Argonne Tandem Linac Accelerator System and the Holifield Radioactive Ion Beam facilities measured as a percentage of the scheduled delivered beam considered effective for each facility. | Achieve at least 80% of the integrated delivered beam used effectively for all experiments run at each of the Argonne Tandem Linac Accelerator System and the Holifield Radioactive Ion Beam facilities measured as a percentage of the scheduled delivered beam considered effective for each facility. |

**Subprograms**

To accomplish its mission and address the scientific challenges described above, the Nuclear Physics program is organized into five subprograms: Medium Energy Nuclear Physics, Heavy Ion Nuclear Physics, Low Energy Nuclear Physics, Nuclear Theory, and Isotope Development and Production for Research and Applications.

- The *Medium Energy* subprogram primarily explores the frontier of QCD with research conducted at two NP national user facilities and other facilities worldwide. The Continuous Electron Beam Accelerator Facility (CEBAF) at the Thomas Jefferson National Accelerator Facility (TJNAF or JLab) provides high quality beams of polarized electrons that allow scientists to extract information on the quark and gluon structure of protons and neutrons. CEBAF also uses polarized electrons to make precision measurements of parity violating processes that can provide information relevant to the development of the New Standard Model. The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL) provides colliding beams of spin-polarized protons to probe the spin structure of the proton, another important aspect of the QCD frontier. This subprogram supports one university Center of Excellence with infrastructure capabilities to develop advanced instrumentation and accelerator equipment.
- The *Heavy Ion* subprogram also investigates the frontier of QCD, but with a different approach—by trying to recreate and characterize new and predicted forms of matter and other new phenomena that might occur in extremely hot, dense nuclear matter and which have not existed since the Big Bang. Measurements are carried out primarily using relativistic heavy ion collisions at RHIC. Participation in the heavy ion program at the Large Hadron Collider (LHC) at the European Organization for Nuclear Research (CERN) provides U.S. researchers the opportunity to search for new states of matter under substantially different initial conditions than those provided by RHIC, yet still provide information regarding the matter that existed during the infant universe.
- The *Low Energy* subprogram studies the frontiers of Nuclear Structure and Astrophysics and Fundamental Symmetry and Neutrinos. Two NP national user facilities are pivotal in making progress in these frontiers. The Argonne Tandem Linac Accelerator System (ATLAS) at Argonne National Laboratory (ANL) is used to study questions of nuclear structure by providing high-quality beams of all the stable elements up to uranium and selected beams of short-lived nuclei for experimental studies of nuclear properties under extreme conditions and reactions of interest to nuclear astrophysics. The Holifield Radioactive Ion Beam Facility (HRIBF) at Oak Ridge National Laboratory (ORNL) provides beams of short-lived radioactive nuclei that scientists use to study exotic nuclei that do not normally exist in nature. HRIBF is also used to explore reactions of interest to nuclear astrophysics. The future Facility for Rare Isotope Beams (FRIB) is a next-generation machine that will advance the understanding of rare nuclear isotopes and the evolution of the cosmos. The subprogram supports four university Centers of Excellence, three with unique low energy accelerator facilities and one with infrastructure capabilities for developing advanced instrumentation. The program also partners with the National Reconnaissance Office and the United States Air Force to support limited operations of the 88-Inch Cyclotron at the Lawrence Berkeley National Laboratory (LBNL) for a small in-house research program and to meet national security needs.

  Also within the portfolio of this subprogram are experiments designed to develop a better understanding of the properties of neutrinos and, in particular, of their masses. This science is typically explored with large detectors buried underground to shield them so that they can detect rare particle signals. Measurements of symmetry properties, particularly the symmetry properties of the neutron, are carried out by nuclear physicists at the Spallation Neutron Source (SNS) at ORNL.

- The *Nuclear Theory* subprogram provides the theoretical underpinning needed to support the interpretation of a wide range of data obtained from all the other NP subprograms and to advance new ideas and hypotheses that stimulate experimental investigations. This subprogram supports the Institute for Nuclear Theory (INT) at the University of Washington, where leading nuclear theorists are assembled from across the Nation to focus on key frontier areas in nuclear physics. The subprogram also collects, evaluates, and disseminates nuclear physics data for basic nuclear research and for applied nuclear technologies with its support of the National Nuclear Data Center (NNDC). The extensive nuclear databases produced by this effort are an international resource consisting of carefully organized scientific information gathered from over 50 years of low-energy nuclear physics research worldwide.
- The *Isotope Development and Production for Research and Applications* subprogram supports the production and development of production techniques of radioactive and stable isotopes that are in short supply. Isotopes are high-priority commodities of strategic importance for the Nation and are essential for energy, medical, and national security applications and for basic research. A goal of the program is to make critical isotopes more readily available to meet domestic U.S. needs. This subprogram is steward of the Isotope Production Facility (IPF) at Los Alamos National Laboratory (LANL), the Brookhaven Linear Isotope Producer (BLIP) facility at BNL, and hot cell facilities for processing isotopes at ORNL, BNL, and LANL. The subprogram also coordinates and supports isotope production at a suite of university, national laboratory, and commercial accelerator and reactor facilities throughout the Nation to promote a reliable supply of domestic isotopes. The National Isotope Data Center (NIDC) at ORNL manages the coordination of isotope production across the many facilities and the business operations of the sale and distribution of isotopes.

### Benefits

Nuclear science basic research is inherently relevant to a broad suite of applications that are important to the Nation. The advancement of knowledge of nuclear matter and its properties is intertwined with nuclear power, nuclear medicine, national security, the environmental and geological sciences, and isotope production. The NP program develops advanced instrumentation, accelerator technologies and techniques, and analytical and computational techniques that are needed for nuclear science research and which have broad societal and economic benefits.

History shows that research into the nucleus has led to a number of valuable applications with practical benefits to society. The realization that the nucleus contains a tremendous amount of energy led to the development of both nuclear power and the atomic bomb. Some of the cutting-edge instrumentation being developed for nuclear physics experiments, such as high-resolution gamma ray detectors, can provide improved imaging techniques with important applications in combating terrorism. The discovery and understanding of nuclear spin made possible the development of magnetic resonance imaging for medical use. Medical imaging, cancer therapy, and biochemical studies all rely on isotopes produced in accelerators that were first developed for nuclear research. Particle beams are used for cancer therapy and in a broad range of materials science studies.

Valuable applications have resulted from research into isotopes and nuclear radiation, which made possible the entire field of nuclear medicine used today in both the diagnosis and treatment of disease. Each day, over 40,000 medical patients receive nuclear medicine procedures. R&D investment has fueled the development of new isotopes and applications, including those for heart and lung imaging, cancer therapy, smoke detectors, neutron detectors, special nuclear material and explosive detection, oil exploration, industrial radiography, and tracers for climate change. The federal support of isotope development and production has reduced health care costs; for example, it has been demonstrated that the use of myocardial perfusion heart imaging in emergency department chest pain centers can reduce duration of stay on average from 1.9 days to 12 hours with a simultaneous reduction in charges. The applications resulting from isotope research have improved the ability of physicians to diagnose illnesses and improved the quality of life for innumerable patients, while at the same time strengthening national security.

Yet another societal benefit of the NP program is the boost to the Nation's R&D workforce through its support of undergraduate researchers, graduate students working toward an advanced degree, and postdoctoral associates developing their research and management expertise. These researchers provide new talent in research and help meet the demand for skilled personnel in a wide variety of technical, medical, security, and industrial fields that require the unique problem-solving abilities and the computational and technical skills developed through an education and experience in nuclear science. Approximately half of the scientists trained as nuclear physicists are found in such diverse areas as energy, nuclear medicine, commerce, medical physics, space exploration, finance, and national security.

## Program Planning and Management

To ensure that funding is allocated as efficiently as possible, the NP program has developed a system of planning and priority setting that relies heavily on input from groups of outside experts. NP has also instituted a number of peer review and oversight measures designed to assess productivity and maintain effective communication and coordination among participants in NP activities. On an as-needed basis, the program has taken the initiative to establish working groups amongst federal agencies to tackle issues of common interest and enhance communication. The NP program takes all of this input into account in its budget requests, making decisions to maximize scientific impact, productivity, quality, and cost-effectiveness within the resources available.

The NP program works closely with NSF to jointly charter the Nuclear Science Advisory Committee (NSAC) for advice regarding compelling opportunities and productivity of the national nuclear science program. NP develops its strategic plan for the field with input from the scientific community via long range plans produced by NSAC every five to six years. These plans perform retrospective assessments of major accomplishments, assess and identify scientific opportunities, and set priorities for the next decade. NSAC provides NP with additional guidance in the form of reviews of subfields, special interest topics, and assessment of the management of the NP program itself. Over the past few years, NSAC has provided guidance regarding opportunities in neutrino science, performance measures to assess productivity of the field, and the effectiveness of the NP program management through a Committee of Visitors review. Ongoing NSAC activities currently include the prioritization of research opportunities with isotopes and the development of a long-term strategic plan for isotope production.

NP strategic plans are also influenced by National Academies reports and Office of Science and Technology Policy (OSTP) Interagency Working Group (IWG) efforts. The 2007 National Academies study *Advancing Nuclear Medicine through Innovation*[a] motivated NP to establish a federal working group with the National Institutes of Health (NIH), along with the Office of Science (SC) Office of Biological and Environmental Research, to better coordinate radioisotope production and to address other issues important to nuclear medicine. The National Academies is embarking on a new decadal study of nuclear science in 2009. In order to optimize interagency activities, NP is involved in two OSTP IWG's: *The Physics of the Universe* and *Large Scale Science.*

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[a] http://dels.nas.edu/dels/rpt_briefs/advancing_nuclear_medicine.pdf

The NP program peer reviews all of its activities. Annual science and technology reviews of the national user facilities and isotope production facilities with panels of international peers assess operations, performance, and scientific productivity. These results influence budget decisions and the NP program's assessment of the laboratory performance documented in annual SC laboratory appraisals. Annual reviews of instrumentation projects, conducted by international experts, focus on scientific merit, technical status and feasibility, cost and schedule, and effectiveness of management organizations. The NP program conducted 17 reviews with panels of international experts in FY 2008. Performance of instrumentation projects are also assessed on a monthly and quarterly basis.

One of the most pressing priority-setting issues at the national user facilities is how to allocate available beam time, or time spent doing experiments on a facility's accelerator. Facility directors seek advice from Program Advisory Committees (PACs) to determine the allocation of this scarce scientific resource. The PACs review research proposals requesting resources and time at the facilities and then provide advice on the scientific merit, technical feasibility, and personnel requirements of the proposals.

The university grants program is proposal driven. The Nuclear Physics program funds the best and most promising of those ideas submitted in response to grant solicitation notices. Proposals are reviewed by external scientific peers and competitively awarded according to the guidelines published in 10 CFR 605. The quality and productivity of university grants are peer reviewed on a three-year basis. Laboratory groups performing research are peer reviewed on a four-year basis to examine the quality of research and to identify needed changes, corrective actions, or redirections of effort. Funding decisions in this budget request are influenced by the results of these periodic peer reviews of the national laboratory research efforts. The most recent review of laboratory research groups was in 2008, for the Heavy Ion subprogram.

**Basic and Applied R&D Coordination**

The knowledge, data, techniques, and methods of nuclear science are utilized in a broad portfolio of applications, including energy, waste disposal, nuclear medicine, commerce, medical physics, space exploration, finance, geology, environmental sciences, national security, and others. NP supports targeted initiatives in Applications of Nuclear Science and Technology. The primary goal of these initiatives is to pursue forefront nuclear science research and development important to the NP mission, but inherently relevant to applications. These initiatives are peer reviewed with participation from relevant federal agencies that directly support, and researchers that conduct, the applied sciences. The integration of the underpinning nuclear science advances resulting from innovative basic research to the applied sciences optimizes communication, cost effectiveness, performance, and technology transfer.

The Isotope Development and Production for Research and Applications subprogram is an excellent example of basic and applied R&D coordination. The subprogram produces commercial and now research isotopes that are important for basic research and applications. Since the program was transferred from the Office of Nuclear Energy to NP in FY 2009, NP has taken significant steps in aligning the industrial and research stakeholders of the isotope program with each other and with the nuclear science research community, all of whom can contribute collectively in advancing the technology of this field. NP sponsored a workshop in August 2008 to bring together all the stakeholder communities in the production and use of radioactive and stable isotopes. A report entitled *Workshop on the Nation's Needs for Isotopes: Present and Future*[a] documents the proceedings and outcomes of this workshop. Working with industry, NP has defined a path forward for ensuring the long-term availability of Californium-252, an isotope of strategic and economic importance to the Nation. NP is working with

[a] http://www.sc.doe.gov/np/program/isotope.html

NIH to develop strong communications and a mechanism for developing plans and priorities regarding medical isotope production. Research was initiated in FY 2009 to support the development of alternative production and extraction techniques of stable and radioactive isotopes and is continued in FY 2010. Also continued in FY 2010 is research that was initiated in FY 2009 to support the production of research isotopes identified by NSAC as needed for high priority research opportunities across a broad range of scientific disciplines.

**Budget Overview**

Today, NP is the largest federal steward for basic research in nuclear science, operating four national user facilities, as well as supporting isotope production and development for the Nation. The FY 2010 budget request of $552,000,000 is designed to optimize, within these resources and in the context of peer review, the scientific productivity of the program by ensuring a proper balance of research workforce, facility operations, and investments in advanced technology and capabilities.

The heart of the Nuclear Physics program is the group of highly trained scientists who conceive, plan, execute, and interpret the numerous experiments carried out at various nuclear physics facilities. The NP program supports scientists at both universities and national laboratories and is involved in a variety of international collaborations, and supports approximately two-thirds of the Nation's university researchers and graduate students who are doing fundamental nuclear physics research. More than 2,000 researchers and students at approximately 100 U.S. academic, federal, and private-sector institutions are supported. Research activities are conducted at approximately 85 academic institutions located in 34 states and the District of Columbia, as well as at 9 DOE laboratories in 8 states. Approximately 80 Ph.D. degrees are granted annually to students for research supported by the program. Six university Centers of Excellence provide unique hands-on training opportunities for junior scientists. The Outstanding Junior Investigator (OJI) program, initiated in FY 2000, makes approximately three new awards each year to early career tenure-track faculty and has been very successful in identifying, recognizing, and supporting promising junior university faculty and future leaders of the field.

NP supports research groups at nine national laboratories: Argonne, Brookhaven, Idaho, Thomas Jefferson, Los Alamos, Lawrence Berkeley, Lawrence Livermore, Oak Ridge and Pacific Northwest National Laboratories. National laboratory research is guided by the DOE mission and priorities and is the underpinning of strategic core competencies needed for the NP program. The national laboratory scientists work and collaborate with academic scientists, other national laboratory experimental researchers, and those carrying out theoretical investigations. The national laboratory scientists collect and analyze data as well as support and maintain the detectors and facilities used in these experiments. The national laboratories also provide state-of-the-art resources for the detector and accelerator R&D that paves the way for future upgrades and new facilities.

Investigating the frontiers of nuclear physics requires being able to accelerate various particles, such as protons, electrons, or a variety of ions, up to nearly the speed of light, smashing them into other particles, and then observing the results of the collisions. Exploring the various areas of nuclear physics demands having a variety of accelerators, each designed to examine the subatomic world in its own unique way and containing a variety of particle detectors and other equipment. Thus, NP supports a suite of facilities that complement one another and provide a variety of approaches to producing and collecting data about matter at the level of the nucleus, as well as the sub-nuclear level. The necessary equipment is large, complex, and expensive to build and operate, and thus it accounts for a significant portion of the program's budget. NP also supports collaborative work at foreign accelerator facilities, as well as joint development of instrumentation.

NP supports four national user facilities (RHIC, CEBAF, ATLAS, and HRIBF), each with capabilities found nowhere else in the world, that provide research time for scientists at universities and other federal laboratories. These major international facilities provide research beams for a user community of over 3,000 scientists from all over the world, with more than 2,000 of the users utilizing RHIC and CEBAF. Approximately 40% of the users are from institutions outside of the U.S., and often provide experimental equipment or instrumentation. A number of other SC programs, DOE offices (National Nuclear Security Administration and Nuclear Energy), federal agencies (NSF, NASA, and Department of Defense), and industries use the NP user facilities to carry out their own programs.

The FY 2010 budget request will support near optimal levels of operations at the national user facilities allowing progress towards achieving performance goals defined by the 2008 *Report to NSAC of the Subcommittee on Performance Measures*[a] for nuclear science. The facilities will provide an estimated 19,930 hours of beam time for research, an increase of ~2,285 hours compared with the anticipated beam hours in FY 2009. The major scientific user facilities will be maintained and operated so that the unscheduled operational downtime will be kept to less than 20%, on average, of total scheduled operating time. Investments will be made in programmatic infrastructure, facility equipment, and accelerator improvement projects that will increase reliability, cost-effectiveness, and productivity, and provide new capabilities to pursue high discovery science.

The only investment in construction is the continuation of the 12 GeV CEBAF Upgrade project, the highest priority in the NSAC Long Range Plan for Nuclear Science. Conceptual design and R&D also continue for the proposed Facility for Rare Isotope Beams (FRIB), a next generation nuclear structure and astrophysics machine that will map out the nuclear landscape. Approximately 4% of the total budget is invested in a handful of small-scale Major Items of Equipment (MIE) projects, all less than $20,000,000, in order to position the program strategically for the future to address compelling scientific opportunities identified by NSAC. The majority of these MIEs are collaborative in nature, with the DOE investment leveraged by contributions from other agencies and international partners. Two new MIEs are initiated in FY 2010: the STAR Heavy Flavor Tracker to study the new hot, dense matter created at RHIC, and the Rare Isotope Beam Science Initiatives to invest in forefront science opportunities at world-leading rare isotope beam facilities around the world.

### Significant Program Shifts

The Isotope Production and Applications program was transferred from the Office of Nuclear Energy to NP in the FY 2009 Appropriation. The budget request for this program is presented in FY 2010 reflecting the approach of the rest of the Nuclear Physics subprograms that focus on research and operations, and the program is renamed “Isotope Development and Production for Research and Applications” to more accurately reflect its mission.

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[a] http://www.sc.doe.gov/np/nsac/nsac.html

## Medium Energy Nuclear Physics

## Funding Schedule by Activity

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Medium Energy Nuclear Physics | | | |
| Research | | | |
| University Research | 17,712 | 19,009 | 20,443 |
| National Laboratory Research | 15,235 | 17,848 | 19,664 |
| Other Research[a] | 519 | 5,936 | 7,048 |
| Total, Research | 33,466 | 42,793 | 47,155 |
| Operations | | | |
| TJNAF Operations | 71,740 | 78,959 | 83,854 |
| Bates Facility | 2,000 | — | — |
| Total, Operations | 73,740 | 78,959 | 83,854 |
| Total, Medium Energy Nuclear Physics | 107,206 | 121,752 | 131,009 |

### Description

The Medium Energy Nuclear Physics subprogram focuses primarily on questions having to do with Quantum Chromodynamics (QCD) and the behavior of quarks inside protons and neutrons, although it touches on all three scientific frontiers. Specific questions that are being addressed include: *What is the internal landscape of the nucleons? What does QCD predict for the properties of strongly interacting matter? What governs the transition of quarks and gluons into pions and nucleons? What is the role of gluons and gluon self-interactions in nucleons and nuclei?* One major goal, for example, is to achieve an experimental description of the substructure of the proton and the neutron. In pursuing that goal the Medium Energy subprogram supports different experimental approaches that seek to determine such things as: the distribution of up, down, and strange quarks in the nucleons; the roles of the gluons that bind the quarks; the role of the "sea" of virtual quarks and gluons, which makes a significant contribution to the properties of protons and neutrons; the effects of the quark and gluon spins within the nucleon; and the effect of the nuclear environment on the quarks and gluons. The subprogram also measures the excited states of hadrons (composite particles made of quarks, including nucleons) in order to identify which properties of QCD determine the dynamic behavior of the quarks.

The subprogram supports investigations into a few aspects of the second frontier, nuclei and nuclear astrophysics, such as the question: *What is the nature of the nuclear force that binds protons and neutrons into stable nuclei?* The subprogram also examines certain aspects of the third area, fundamental symmetries and nuclei, including the questions: *Why is there now more visible matter than antimatter in the universe? What are the unseen forces that were present at the dawn of the universe, but disappeared from view as it evolved?*

[a] In FY 2008, $3,691,000 was transferred to the SBIR program and $1,130,000 was transferred to the STTR program. This activity includes $3,663,000 for SBIR and $1,246,000 for STTR in FY 2009 and $4,259,000 for SBIR and $1,346,000 for STTR in FY 2010.

Funding supports both research and operations of the subprogram's primary research facility, CEBAF, while only research is supported at RHIC. Research support at both facilities includes the laboratory and university personnel needed to implement and run experiments and to conduct the data analysis necessary to publish results. Individual experiments are supported at the High Intensity Gamma Source (HIγS) at Triangle University Nuclear Laboratory, at Fermi National Accelerator Laboratory (Fermilab), and at several facilities in Europe. All these facilities produce beams of sufficient energy (that is, of small enough wavelength) to see details smaller than the size of a nucleon.

**Selected FY 2008 Accomplishments**

- A recent measurement from TJNAF may have a bearing on the property of neutron stars as well as advancing our knowledge about the interactions of neutrons and protons inside nuclei. This measurement found that high momentum protons inside a nucleus are 20 times more likely to pair with neutrons than other protons. A theoretical calculation that includes this pairing effect inside neutron stars indicates that it could have a significant effect on the star's structure.
- Significant progress has been made on one of NP's research milestones to determine the gluon contribution to the proton's spin. A new global analysis of the world's existing data that includes recent measurements made at RHIC and TJNAF indicates that while the magnitude of the gluon polarization inside the proton is small, less than 10%, the polarization may change sign. If true, this change in sign would be important in understanding how the gluons are polarized. Resolving this question will require the higher statistical data expected from RHIC in the next few years.
- TJNAF has developed a new mode of running CEBAF in which the two linear accelerators are operated at different energies. This new operating mode allows the facility greater flexibility in providing optimized beam energies and polarizations to the three halls increasing overall scientific productivity of the facility.

## Detailed Justification

| (dollars in thousands) | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **Research** | **33,466** | **42,793** | **47,155** |
| ▪ **University Research** | **17,712** | **19,009** | **20,443** |

These activities comprise a broad program of research, and include support of about 180 scientists and 150 graduate students at 38 universities in 22 states and the District of Columbia. Of this amount, $2,000,000 supports the MIT Research and Engineering (R&E) Center that has specialized infrastructure for fabrication of scientific instrumentation.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **National Laboratory Research** | **15,235** | **17,848** | **19,664** |

This funding supports research groups at TJNAF, BNL, ANL, and LANL that carry out research at CEBAF and RHIC. It also supports two experiments at Fermilab and nuclear research using laser trapping technology at ANL.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| • **TJNAF Research** | **6,141** | **6,150** | **7,153** |

This funding allows TJNAF staff to carry out their research efforts in the CEBAF experimental Halls A, B, and C. The remaining approximately 70% of the support for these staff is under Experimental Support discussed below. It also supports an active visiting scientist program at the

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|

laboratory and bridge positions with regional universities. The $1,003,000 increase in FY 2010 will add new staff for the new Hall D experimental hall to be built as part of the 12 GeV CEBAF Upgrade, and restore the visiting scientist and university programs that have been reduced the past several years.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| • **Other National Laboratory Research** | **9,094** | **11,698** | **12,511** |

Argonne National Laboratory scientists continue their primary research program at TJNAF, as well as one experiment at Fermilab, to search for a detailed understanding of the internal quark-gluon structure of the nucleon. ANL scientists are also using their unique laser atom-trapping technique to make a precision measurement of the atomic electric dipole moment that could shed light on the excess of matter over antimatter in the universe.

Support is provided to the RHIC spin physics research groups at BNL and LANL, which have important roles and responsibilities in the RHIC program.

At LANL, support is provided to allow scientists and collaborators to complete the Fermilab MiniBooNE anti-neutrino running and analysis, and to continue to develop a transition plan for future neutrino research.

| | | | |
|---|---|---|---|
| ▪ **Other Research** | **519** | **5,936** | **7,048** |
| • **SBIR/STTR and Other** | **519** | **5,686** | **6,418** |

In FY 2008, $3,691,000 was transferred to the Small Business Innovation Research (SBIR) program and $1,130,000 was transferred to the Small Business Technology Transfer (STTR) program. This activity includes $3,663,000 for SBIR and $1,246,000 for STTR in FY 2009 and $4,259,000 for SBIR and $1,346,000 for STTR in FY 2010 as well as other established obligations that the Medium Energy Nuclear Physics subprogram must meet.

| | | | |
|---|---|---|---|
| • **Accelerator R&D Research** | **—** | **250** | **630** |

The Medium Energy Accelerator R&D Research at universities and laboratories will develop the knowledge, technologies, and trained scientists to design and build the accelerator facilities needed to carry out a forefront experimental program and to accomplish the DOE programmatic mission in nuclear physics.

| | | | |
|---|---|---|---|
| **Operations** | **73,740** | **78,959** | **83,854** |
| ▪ **TJNAF Operations** | **71,740** | **78,959** | **83,854** |

Funding supports CEBAF operations and Experimental Support for 5,110 hours and 3-Hall operations schedule, a 3% increase from estimated running in FY 2009, increasing the utilization of the facility to 85%.

| | | | |
|---|---|---|---|
| • **TJNAF Accelerator Operations** | **45,510** | **49,900** | **54,540** |

Support is provided for operation ($49,000,000), capital investments ($840,000) and accelerator improvements ($3,200,000) to the CEBAF accelerator complex, and to maintain efforts in developing advances in superconducting radiofrequency technology ($1,500,000). A significant

(dollars in thousands)

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|

part of the increase in FY 2010 is due to power costs which are expected to be about $1,600,000 over FY 2009, which was up $2,900,000 over FY 2008.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| CEBAF Hours of Operation with Beam | | | |
| Achieved Operating Hours | 3,914 | N/A | N/A |
| Planned Operating Hours | 3,500 | 4,965 | 5,110 |
| Optimal Hours | 5,600 | 5,980 | 5,980 |
| Percent of Optimal Hours | 70% | 83% | 86% |
| Unscheduled Downtime | 8.0% | N/A | N/A |
| Number of Users | 1,313 | 1,350 | 1,390 |

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| • **TJNAF Experimental Support** | **26,230** | **29,059** | **29,314** |

The FY 2010 request supports Experimental Support ($24,614,000) efforts at the level needed for 5,110 hours and a 3-Hall operations schedule. Support is provided for the scientific and technical staff, materials, and services for CEBAF, and to integrate assembly, modification, and disassembly of large and complex experiments. This includes the delivery or dismantling of cryogenic systems, electricity, water for cooling, radiation shielding, and special equipment for specific experiments.

FY 2010 funds for capital equipment ($4,700,000) are used for fabrication, assembly and installation of scientific instrumentation in the experimental halls, such as polarized targets, spectrometer systems, and new detectors. The $Q_{weak}$ detector system being fabricated will perform a precision measurement of the weak charge of the proton. This support is necessary to implement high priority experiments in the current 6 GeV experimental program prior to the 12 GeV CEBAF Upgrade project installation.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **Bates Facility** | **2,000** | **—** | **—** |

User facilities operations of the Bates Linear Accelerator Center at the Massachusetts Institute of Technology were terminated in FY 2005. The final funding increment for transfer of ownership of the facility was provided in FY 2008 as part of the agreement that turned ownership of the facility over to MIT in FY 2009 in exchange for MIT assuming responsibility for all future D&D activities and liability for the facility.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **Total, Medium Energy Nuclear Physics** | **107,206** | **121,752** | **131,009** |

## Explanation of Funding Changes

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| **Research** | |
| ▪ **University Research** | |
| The increase in FY 2010 funding will provide additional university support (the equivalent of about nine new grants) for research at TJNAF, RHIC and Fermilab, and revitalization of university equipment and infrastructure. | +1,434 |
| ▪ **National Laboratory Research** | |
| The increase in FY 2010 funding supports the ANL and BNL Medium Energy research groups at levels needed to carryout their existing research programs and support a new experiment at Fermilab and a new experiment at TJNAF. | +1,816 |
| ▪ **Other Research** | |
| • SBIR/STTR and Other increases at levels required proportionate to research and development activities. | +732 |
| • Increased Accelerator R&D research funding is provided for R&D efforts to develop the knowledge, technologies and trained scientists needed to design and build the accelerator facilities in order to accomplish the programmatic mission in nuclear physics, including feasibility efforts associated with a potential Electron-Ion Collider. | +380 |
| **Total, Other Research** | **+1,112** |
| **Total, Research** | **+4,362** |
| **Operations** | |
| ▪ **TJNAF Operations** | |
| • **TJNAF Accelerator Operations** | |
| FY 2010 funding operates CEBAF at levels needed to carry out the highest priority experiments within the current 6 GeV program. Increased funding covers cost of living plus $1,600,000 for increased power costs and a slight increase in operating hours. | +4,640 |
| • **TJNAF Experimental Support** | |
| Increased funding primarily supports additional experimental capital equipment for the highest priority experiments within the current CEBAF 6 GeV program. | +255 |
| **Total, Operations** | **+4,895** |
| **Total Funding Change, Medium Energy Nuclear Physics** | **+9,257** |

## Heavy Ion Nuclear Physics

## Funding Schedule by Activity

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Heavy Ion Nuclear Physics | | | |
| Research | | | |
| University Research | 13,016 | 13,984 | 15,351 |
| National Laboratory Research | 22,896 | 27,174 | 30,494 |
| Other Research[a] | — | 5,612 | 6,817 |
| Total, Research | 35,912 | 46,770 | 52,662 |
| Operations | | | |
| RHIC Operations | 137,041 | 148,859 | 160,180 |
| Other Operations | 9,283 | 4,744 | 6,714 |
| Total, Operations | 146,324 | 153,603 | 166,894 |
| Total, Heavy Ion Nuclear Physics | 182,236 | 200,373 | 219,556 |

### Description

The Heavy Ion Nuclear Physics subprogram focuses on studies of nuclear matter at extremely high densities and temperatures. A new program of research on hot nuclear matter began at the Relativistic Heavy Ion Collider (RHIC) at BNL in 2000 when the first collisions of counter-circulating gold nuclei were observed at beam energies ten times higher than those available at any other facility in the world. At RHIC, beams of gold nuclei are accelerated to close to the speed of light and then slammed head on into one another in order to create extremely high-energy collisions between pairs of gold nuclei. In the aftermath of these collisions researchers have seen signs of the same quark-gluon soup that is believed to have existed shortly after the Big Bang. With careful measurements, scientists accumulate data that offer insights into those brief moments immediately following the creation of the universe and begin to understand how the protons, neutrons, and other bits of normal matter developed from that soup.

The RHIC facility puts heavy ion research at the energy frontier of nuclear physics. RHIC serves two large-scale international experiments called PHENIX and STAR. In these experiments, scientists are now trying to determine the physical characteristics of the recently discovered perfect liquid of quarks and gluons. A 10-fold enhancement in the heavy ion beam collision rate and detector upgrades are expected to be completed within the next 5 years. Accelerator R&D is being conducted at RHIC in a number of advanced areas including cooling of high-energy hadron beams, high intensity polarized electron sources, and high-energy, high-current energy recovery linear (ERL) accelerators. The RHIC facility is used by about 1,200 DOE-, NSF-, and foreign agency-supported researchers.

The Large Hadron Collider (LHC) at CERN offers opportunities for making new discoveries in relativistic heavy ion physics. The LHC will provide a 30-fold increase in center-of-mass energy over what is available now. Scientists are preparing to conduct research using A Large Ion Collider Experiment (ALICE) and the Compact Muon Spectrometer (CMS). U.S. researchers are fabricating a

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[a] In FY 2008, $4,390,000 was transferred to the SBIR program. This activity includes $5,296,000 for SBIR in FY 2009 and $5,481,000 for SBIR in FY 2010.

large Electromagnetic Calorimeter (EMCal) detector to be installed in phases in the ALICE experiment over the next few years. First heavy ion beam operations at the LHC are expected to start in 2010.

The RHIC and LHC research programs are directed primarily at answering the overarching questions that define the first frontier identified by the nuclear science community—Quantum Chromodynamics (QCD). The fundamental questions addressed include: *What are the phases of strongly interacting matter, and what roles do they play in the cosmos? What governs the transition of quarks and gluons into pions and nucleons? What determines the key features of QCD, and what is their relation to the nature of gravity and spacetime?*

**Selected FY 2008 Accomplishments**

- The wealth of heavy ion data from the years of operation of the RHIC collider has appeared in more than 200 scientific publications and these results are leading to a paradigm that the matter produced in highly energetic nucleus-nucleus collisions acts like a perfect liquid with minimum viscosity.

  Scientists are now trying to determine the physical characteristics of this perfect liquid. The temperature is one of the most important of these characteristics, for it is a measure of the average energy of the particles inside this liquid. Energetic photons (or light) emanating from this perfect liquid have been observed. These data suggest that the initial fluid temperature may correspond to an energy of about 600 MeV which is far greater than the critical temperature thought necessary for the formation of the quark-gluon plasma. This is approximately 500,000 times greater than the energy of particles in the core of the sun!

- In FY 2008, RHIC delivered high intensity beams of gold and deuterium ions. RHIC continued to exceed accelerator performance in each successive mode of operations. A new record of delivered luminosity (about 238 inverse nanobarns [$nb^{-1}$ ]) at a beam energy of 100 GeV per nucleon was achieved. This record is almost ten times the delivered luminosity of the previous run with the same colliding beam species of gold on gold in 2004. RHIC has also successfully demonstrated gold ion collisions at very low energy (about 1/2 normal injection energy of 9 GeV). Future low energy, heavy ion beam R&D could allow scientists to search for the postulated critical point in the QCD phase diagram of nuclear matter.

- Increased beam luminosity of heavy ion beams has been successfully demonstrated at RHIC using longitudinal stochastic cooling in one of the accelerator rings. Accelerator scientists expect the planned implementation of longitudinal and transverse stochastic cooling to both accelerator rings, together with a new 56 MHz storage radiofrequency system, will provide a 10-fold increase in gold beam luminosity by 2012 without the need for the previously envisioned RHIC II upgrade, saving the federal government an anticipated $100,000,000 investment.

## Detailed Justification

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| **Research** | **35,912** | **46,770** | **52,662** |
| ▪ **University Research** | **13,016** | **13,984** | **15,351** |

Research support is provided for about 120 scientists and 90 graduate students at 27 universities in 21 states. Funding supports research efforts at RHIC and the continuation of a modest program at the LHC. The university groups provide scientific personnel and graduate students needed for running

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |

the RHIC and LHC heavy ion experiments, data analysis and publishing RHIC results, and designing and fabricating the RHIC and LHC heavy ion detector upgrades.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **National Laboratory Research** | **22,896** | **27,174** | **30,494** |

This funding supports research groups at BNL, LBNL, LANL, ORNL, and LLNL that carry out research primarily at RHIC and a modest program at the LHC. These scientists provide essential personnel for designing, fabricating, and operating the RHIC detectors; analyzing RHIC data and publishing scientific results; conducting R&D of innovative detector designs; project management and fabrication of MIEs and planning for future experiments. Also, BNL and LBNL provide substantial computing infrastructure for terabyte-scale data analysis and state-of-the-art facilities for detector and instrument development. During FY 2008, the five laboratory groups were reviewed and evaluated based on the significance of their accomplishments and the merit of future programs; the results of the review influence funding decisions of individual groups.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| • **BNL RHIC Research** | **9,187** | **9,737** | **8,982** |

The FY 2010 budget request allows BNL scientists to continue to provide maintenance and infrastructure support of the RHIC experiments, to develop and implement new instrumentation, to effectively utilize the beam time for research, to train junior scientists, and to develop the computing infrastructure for use by the scientific community. The PHENIX Silicon Vertex Tracker (VTX) MIE, a joint project with the Japanese, received its final funding increment under the American Recovery and Reinvestment Act (Recovery Act) and is planned for completion in FY 2010. It is a barrel of silicon pixel and strip detectors that will provide precision measurement of heavy quark production to study the thermalization process in the heavy ion collisions. The PHENIX Forward Vertex Detector (FVTX) MIE also received its final funding under the Recovery Act and continues fabrication in FY 2010. Important for both the heavy ion and spin programs, this detector will provide vertex tracking capabilities to PHENIX by adding two silicon endcaps. The STAR Heavy Flavor Tracker (HFT) is a new MIE initiated in FY 2010. It is an ultra-thin, high-precision tracking detector that will provide direct reconstruction of short-lived particles containing heavy quarks. Support is also provided in FY 2010 for continued studies directed at developing the scientific case for a potential electron-heavy ion collider facility.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| • **Other National Laboratory Research** | **13,709** | **17,437** | **21,512** |

Researchers at LANL, LBNL, LLNL, and ORNL provide unique expertise and facilities for RHIC and LHC detector upgrades and analyses of data. For example, at LBNL, the large scale computational system, Parallel Distributed Systems Facility (PDSF), is a major resource used for the analysis of RHIC and LHC data, in alliance with the National Energy Research Scientific Computing Center (NERSC). At LLNL, computing resources are made available for the PHENIX and LHC data analysis. LBNL staff led the fabrication of the LHC Heavy Ion MIE, a joint project with France and Italy that adds a large Electromagnetic Calorimeter (EMCal) to the CERN ALICE experiment to provide the capability to study energy loss in the quark gluon plasma. This support continues in FY 2010 according to the planned profile.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| ▪ **Other Research** | **—** | **5,612** | **6,817** |
| • **SBIR and Other** | **—** | **5,362** | **5,547** |

In FY 2008, $4,390,000 was transferred to the Small Business Innovative Research (SBIR) program. This activity includes $5,296,000 for SBIR in FY 2009 and $5,481,000 for SBIR in FY 2010 as well as other established obligations that the Heavy Ion Nuclear Physics subprogram must meet.

| | | | |
|---|---|---|---|
| • **Accelerator R&D Research** | **—** | **250** | **1,270** |

The Heavy Ion Accelerator R&D research at universities and laboratories will develop the knowledge, technologies, and trained scientists to design and build the accelerator facilities needed to carry out a forefront experimental program and to accomplish its DOE programmatic mission in nuclear physics. This includes efforts associated with establishing technical feasibility of a possible future Electron-Ion Collider.

| | | | |
|---|---|---|---|
| **Operations** | **146,324** | **153,603** | **166,894** |
| ▪ **RHIC Operations** | **137,041** | **148,859** | **160,180** |

RHIC operations are supported for an estimated 3,720 hour operating schedule (91% utilization) in FY 2010 that greatly expands the scientific opportunities. The Electron Beam Ion Source (EBIS) construction project is completed in FY 2010 and its implementation, along with detector upgrades, will allow the RHIC program to make incisive measurements leading to more definitive conclusions on the discovery of strongly interacting quark gluon matter and to establish whether other phenomena, such as a color glass condensate or chiral symmetry restoration exist in nature.

| | | | |
|---|---|---|---|
| • **RHIC Accelerator Operations** | **106,158** | **115,460** | **124,430** |

Support is provided for the operation ($119,130,000), capital investments ($1,500,000), and accelerator improvement projects ($3,800,000) of the RHIC accelerator complex. This includes the Tandem (that will be replaced by the Electron Beam Ion Source, which will be completed in FY 2010), Booster, and AGS accelerators that together serve as the injector for RHIC. Funding will support about 3,720 hours of operations, an increase of 1,240 hours compared to FY 2009. Measurements of rare particles will require higher integrated beam luminosity and support is provided for R&D of electron beam cooling and other luminosity enhancement technologies.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| RHIC Hours of Operation with Beam | | | |
| Achieved Operating Hours | 2,566 | N/A | N/A |
| Planned Operating Hours | 3,192 | 2,480 | 3,720 |
| Optimal Hours | 4,100 | 4,100 | 4,100 |
| Percent of Optimal Hours | 80% | 61% | 91% |
| Unscheduled Downtime | 16.7% | N/A | N/A |
| Number of Users | 1,200 | 1,200 | 1,200 |

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| | (dollars in thousands) | | |
| • **RHIC Experimental Support** | **30,883** | **33,399** | **35,750** |

Support is provided for the operation, maintenance, improvement, and enhancement of the RHIC experimental complex, including the STAR and PHENIX detectors, experimental halls, computing center, and support for users. The STAR and PHENIX detectors provide complementary measurements, with some overlap in order to cross-calibrate the measurements. Base capital equipment funding is increased relative to FY 2009 to provide the support for maintaining computing capabilities at the RHIC Computing Facility (RCF) and for instrumentation.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **Other Operations** | **9,283** | **4,744** | **6,714** |

The Nuclear Physics program provides funding to BNL for minor new fabrications, needed laboratory equipment (including general purpose equipment), and other expenses. Funding of this type is essential for maintaining the productivity and usefulness of DOE-owned facilities and for meeting its requirement for safe and reliable facilities operation.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **Total, Heavy Ion Nuclear Physics** | **182,236** | **200,373** | **219,556** |

## Explanation of Funding Changes

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| **Research** | |
| ▪ **University Research** | |
| The increase for University Research grants in FY 2010 is needed to support data collection with STAR and PHENIX, as well as a modest effort directed towards research at the LHC heavy ion program. Funds also support revitalization of university infrastructure and equipment. | +1,367 |
| ▪ **National Laboratory Research** | |
| • BNL RHIC Research is decreased relative to FY 2009 due to completion of funding for the PHENIX Silicon VTX and the PHENIX FVTX detector MIEs in FY 2009. Partially offsetting those decreases is an increase to initiate the STAR HFT MIE. | -755 |
| • Other National Laboratory Research is increased in FY 2010 to ensure adequate support to the RHIC experiments and its upgrades, to effectively utilize the beam time for research, and to train students and junior scientists. Funding is provided for researchers to meet the U.S. commitments to the LHC heavy ion program. In addition, funding is increased by $1,000,000 for the continued fabrication of the LHC Heavy Ion MIE according to the planned profile. | +4,075 |
| **Total, National Laboratory Research** | **+3,320** |

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| ▪ **Other Research** | |
| • SBIR and Other increases at levels required proportionate to R&D activities. | +185 |
| • Accelerator R&D Research is increased in FY 2010 to develop the knowledge, technologies, and trained scientists needed to design and build accelerator facilities to accomplish DOE's programmatic mission in nuclear physics, including efforts aimed at establishing technical feasibility of a possible future Electron Ion Collider. | +1,020 |
| **Total, Other Research** | **+1,205** |
| **Total, Research** | **+5,892** |
| **Operations** | |
| ▪ **RHIC Operations** | |
| • RHIC Accelerator Operations: The FY 2010 request supports an approximate 50% increase in operating hours to meet the program's scientific goals and performance measures, allowing the RHIC facility to operate at 91% utilization. An increase of $800,000 is provided for accelerator improvement projects (AIP) to impact operational efficiencies and provide new capabilities. Capital Equipment is increased by $430,000 to replace or upgrade aging equipment. | +8,970 |
| • RHIC Experimental Support is increased commensurate with the increase in operating hours to provide for experimental scientific/technical staff, materials and supplies, and capital equipment to effectively support the maintenance and operation of the PHENIX and STAR detectors at RHIC during this run. | +2,351 |
| **Total, RHIC Operations** | **+11,321** |
| ▪ **Other Operations** | |
| Increased funding is provided for general purpose equipment at BNL for upgrading and replacing aging laboratory equipment and for other small infrastructure and equipment revitalization within the national laboratory heavy ion complex. | +1,970 |
| **Total, Operations** | **+13,291** |
| **Total Funding Change, Heavy Ion Nuclear Physics** | **+19,183** |

## Low Energy Nuclear Physics

## Funding Schedule by Activity

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Low Energy Nuclear Physics | | | |
| Research | | | |
| University Research | 18,836 | 21,100 | 26,266 |
| National Laboratory Research | 30,808 | 29,470 | 42,213 |
| Other Research[a] | 3,800 | 2,386 | 1,886 |
| Total, Research | 53,444 | 52,956 | 70,365 |
| Operations | 28,835 | 41,662 | 46,451 |
| Total, Low Energy Nuclear Physics | 82,279 | 94,618 | 116,816 |

### Description

The research effort supported by the Low Energy Nuclear Physics subprogram aims primarily at answering the overarching questions associated with the second frontier identified by NSAC—nuclei and nuclear astrophysics. These questions include: *What is the nature of the nuclear force that binds protons and neutrons into stable nuclei and rare isotopes? What is the origin of simple patterns in complex nuclei? What is the nature of neutron stars and dense nuclear matter? What is the origin of the elements in the cosmos? What are the nuclear reactions that drive stars and stellar explosions?* One goal of Low Energy Nuclear Physics is to develop a comprehensive description of nuclei across the entire nuclear chart. The coming decade of nuclear physics studies with rare isotope beams may reveal new nuclear phenomena and structures unlike those that are known from studies using stable nuclei. Experiments measure the cross sections of nuclear reactions that power stars and spectacular stellar explosions and are responsible for the synthesis of the elements. The subprogram also investigates aspects of the third frontier of fundamental symmetries and neutrinos. Questions addressed in this frontier include: *What is the nature of the neutrinos, what are their masses, and how have they shaped the evolution of the universe? Why is there now more visible matter than antimatter in the universe? What are the unseen forces that were present at the dawn of the universe but disappeared from view as the universe evolved?* Neutrinos are now known to have small but none-zero masses. The subprogram seeks to measure, or set a limit on, the neutrino mass and to determine if the neutrino is its own antiparticle. These neutrino properties are believed to play a role in the evolution of the cosmos. Experiments with cold neutrons also investigate the dominance of matter over antimatter in the universe, as well as other aspects of fundamental symmetries and interactions.

Funding supports both research and operations of the subprogram's two major national user facilities, HRIBF and ATLAS. HRIBF and ATLAS serve a research community of close to 700 researchers, including international researchers and those supported by DOE and NSF.

The NP program also supports the LBNL 88-Inch Cyclotron for a small in-house nuclear physics and chemistry research program, while the National Reconnaissance Office (NRO) and U.S. Air Force

[a] In FY 2008, $1,344,000 was transferred to the SBIR program. This activity includes $1,426,000 for SBIR in FY 2009 and $1,476,000 for SBIR in FY 2010.

(USAF) provide support towards improvements in radiation hardness of electronic circuit components against damage caused due to cosmic rays. A Memorandum of Agreement between NP, NRO, and the USAF provides for joint support of the 88-Inch Cyclotron through 2011. In FY 2010, fabrication continues at LBNL for the Gamma Ray Energy Tracking In-Beam Nuclear Array (GRETINA) MIE, a segmented germanium detector array with unparalleled position and energy resolution for nuclear structure studies with fast nuclear beams.

The subprogram also supports accelerator operations at Texas A&M University (TAMU), at the Triangle Universities Nuclear Laboratory (TUNL) at Duke University, and at Yale University for studies in nuclear structure and nuclear astrophysics that are especially suited to university facilities. At the University of Washington, the subprogram supports infrastructure in order to enable scientific instrumentation projects. Each of these university Centers of Excellence has a critical mass of nuclear physics faculty involved in research that is conducted both on and off campus plus about 15-25 graduate students at different stages of their education.

Progress in both nuclear structure and nuclear astrophysics studies depends increasingly upon the availability of rare isotope beams. While the U.S. today has first-generation facilities with capabilities for these studies, a facility with next-generation capabilities for short-lived radioactive beams is needed to maintain a leadership role. A study by the National Academies concluded that such a facility was a priority for the U.S., and the NSAC Long Range Plan recommended its construction. In FY 2008, a Funding Opportunity Announcement invited proposals for a Facility for Rare Isotope Beams (FRIB). Following peer review of the submitted proposals, the DOE selected Michigan State University as the host institution to establish FRIB and site the facility on its campus. In FY 2010 facility-specific R&D and Conceptual Design activities for this facility continue.

In the area of neutrino physics, U.S. researchers at the Kamioka Large Anti-Neutrino Detector (KamLAND) experiment in Japan are continuing to study the properties of anti-neutrinos produced by nuclear power reactors. The experiment is entering a new phase to measure lower-energy solar neutrinos following an upgrade of the detector. In FY 2008, U.S. researchers joined the Italian-lead Cryogenic Underground Observatory for Rare Events (CUORE) experiment at the Gran Sasso Laboratory, to search for evidence that the neutrino is its own antiparticle (a Majorana particle) and determine or set a limit on the effective Majorana mass of the neutrino. In FY 2007, U.S. university scientists began participation in the German-lead Karlsruhe Tritium Neutrino (KATRIN) experiment to determine the mass of the electron neutrino by measuring the beta decay spectrum of tritium.

Finally, the Low Energy subprogram supports studies of fundamental interactions and symmetries using neutrons or nuclei. Sensitive experiments are being prepared to be mounted at the Fundamental Neutron Physics Beamline (FNPB), which will be completed in FY 2010 at the Spallation Neutron Source (SNS).

**Selected FY 2008 Accomplishments**

- An important question for Earth science is to understand the source of heat at the Earth's core and whether nuclear reactions play a role. With data from the KamLAND experiment, researchers recently set an upper limit of 6.2 TW for a possible antineutrino-emitting nuclear reactor at the Earth's center.
- Using novel techniques, researchers have produced and measured radii of two rare isotopes of helium, namely $^{6}$He and $^{8}$He, which led to the counter intuitive result that the charge radius of the heavier $^{8}$He is smaller than that of $^{6}$He. This important result is in good agreement with recent *ab initio* theoretical calculations and provides a critical test of present understanding of the fundamental forces that bind together protons and neutrons in atomic nuclei.

- The purity of rare isotope beams is of crucial importance for research programs in nuclear physics and astrophysics. Scientists at HRIBF at ORNL recently patented a novel beam purification technique that uses lasers to neutralize unwanted negative ions. The technique will be applied to produce almost pure beams of rare isotopes of fluorine, chlorine, and nickel, which are important to nuclear structure physics to better understand the reaction rates for rapid proton capture in nuclei and synthesis of rare proton-rich nuclei.
- The High Intensity Gamma Source (HIγS) facility at the Duke Free Electron Laser Laboratory was upgraded successfully to provide tunable, polarized, nearly mono-energetic gamma-ray beams in the energy range of 2 to 60 MeV. The intensities of these beams are several orders of magnitude larger than those available at other sources. The unique qualities of HIγS beams will allow scientists to study stellar production of carbon and oxygen.

## Detailed Justification

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| **Research** | **53,444** | **52,956** | **70,365** |
| ▪ **University Research** | **18,836** | **21,100** | **26,266** |

Support is provided for the research of about 123 scientists and 97 graduate students at 35 universities to perform research at in-house or national laboratory facilities. FY 2010 funding augments experimental capabilities at research universities and supports the NP workforce at levels needed to reach NSAC performance measures.

University researchers conduct programs using the low energy heavy ion beams and specialized instrumentation at the ATLAS and HRIBF national user facilities. These efforts at the user facilities involve about two-thirds of the university scientists supported by this subprogram.

Accelerator operations are supported for in-house research programs at the facilities at Duke University, TAMU, and Yale University. These small university facilities have well-defined and unique physics programs, providing photons, neutrons, light ion beams, or heavy ion beams; specialized instrumentation; and opportunities for long-term measurements that complement the capabilities of the national laboratory user facilities.

Accelerator and non-accelerator experiments directed at fundamental measurements are supported, such as KamLAND, KATRIN, and studies with cold neutrons at the SNS with the FNPB.

| | | | |
|---|---|---|---|
| ▪ **National Laboratory Research** | **30,808** | **29,470** | **42,213** |

Support is provided for the research programs of scientists at six national laboratories (ANL, BNL, LBNL, LANL, LLNL, and ORNL). Funding decisions are influenced by the results of periodic peer reviews of the national laboratory research groups. Results of these evaluations and the relative ranking of the groups have been factored into the groups' funding in subsequent years.

| | | | |
|---|---|---|---|
| • **National Laboratory User Facility Research** | **11,002** | **9,027** | **8,986** |

ANL researchers use stable and selected radioactive beams from ATLAS coupled to ion traps, Gammasphere, and the Fragment Mass Analyzer for nuclear structure studies. The Advanced Penning Trap measures atomic masses with high precision. ORNL researchers use radioactive beams from the HRIBF and specialized spectrometers to study the nuclear structure of nuclei far

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |

from stability. Specialized equipment is employed, such as a system that integrates gamma-ray and charged-particle detectors with a recoil mass separator. The high-pressure gas target is being utilized in an experimental program in nuclear astrophysics. Additional support for these staff is provided as experimental support discussed under User Facility Operations below.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| • **Other National Laboratory Research** | **19,806** | **20,443** | **33,227** |

Scientists at BNL, LBNL, LLNL, LANL, and ORNL play important roles in several high-priority accelerator- and non-accelerator-based experiments (KamLAND, nEDM and CUORE). R&D activities are also supported for another neutrino-less double beta decay (DBD) experiment based on a different technology. Capital equipment funding is increased in FY 2010 to support the ongoing instrumentation projects according to planned profiles and to initiate a new MIE.

Research efforts relevant to Applications of Nuclear Science and Technology (+$1,527,000) are increased and will be competed among university and laboratory researchers. These initiatives support nuclear science research that is inherently relevant to a broad suite of applications; additional funding is provided for this effort in the Nuclear Theory subprogram for Nuclear Data activities.

The GRETINA MIE is especially important for the study of the nuclear structure of rare isotopes produced in reactions with fast fragmentation beams. FY 2010 is the final year of funding ($430,000) for GRETINA which is scheduled for completion in FY 2011.

Support is provided for groups at BNL, LANL, and LBNL to conclude the analysis of data and publication of results from completed and ongoing neutrino experiments, and develop next generation neutrino experiments.

Support is provided to ORNL to continue to coordinate and play a leadership role in the development of the scientific and experimental program at the FNPB. The FNPB project is a beamline at the SNS that will deliver record peak currents of cold and ultra-cold neutrons for studying the fundamental properties of the neutron, leading to a refined characterization of the weak force. Fabrication of the FNPB began in FY 2004 and will be complete in FY 2010. FNPB received $600,000 under the Recovery Act to complete funding of the project.

In FY 2010, $4,500,000 is provided to pursue the measurement of the electric dipole moment of the neutron (nEDM), a high discovery potential experiment at the FNPB. The nEDM experiment is a joint DOE/NSF experiment. The measurement of a non-zero electric dipole moment of the neutron will significantly constrain extensions of the Standard Model.

In FY 2010, $4,500,000 is provided to continue fabrication of the CUORE experiment to search for neutrino-less double beta decay (DBD). This is a joint DOE/NSF project. R&D also continues on additional technical approaches to DBD.

In FY 2010, $4,200,000 is provided to initiate new Rare Isotope Beam Science Initiatives to support forefront scientific instrumentation opportunities at rare isotope beam facilities around the world.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| | (dollars in thousands) | | |
| ▪ **Other Research** | **3,800** | **2,386** | **1,886** |
| • **Generic Rare Isotope Beam R&D** | **3,800** | **—** | **—** |

In FY 2008, funds were provided for R&D activities aimed at development of generic rare isotope beam capabilities. In FY 2009, these R&D activities became facility-specific and part of the Total Project Cost of the proposed Facility for Rare Isotope Beams, as reflected in Operations below.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| • **SBIR and Other** | **—** | **2,386** | **1,886** |

In FY 2008, $1,344,000 was transferred to the SBIR program. This activity includes $1,426,000 for SBIR in FY 2009, and $1,476,000 for SBIR in FY 2010. Funding is also provided for other established obligations including the Lawrence and Fermi Awards, which provide annual monetary awards to honorees selected by DOE for outstanding contributions to science.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **Operations** | **28,835** | **41,662** | **46,451** |
| ▪ **User Facility Operations** | **25,485** | **30,830** | **33,198** |

In FY 2010, funding supports accelerator operations and experimental support at ATLAS ($16,553,000) providing increased beam hours compared to FY 2009 levels, and the more cost effective 7 day-a-week operations mode. The Californium Rare Ion Breeder Upgrade (CARIBU) AIP project is completed in FY 2010 to enhance the radioactive beam capabilities of ATLAS.

In FY 2010, funding supports accelerator operations and experimental support at HRIBF ($16,645,000) at increased levels in comparison to FY 2009, and with a transition from 5 to 7 day-a-week operations. The facility begins to commission a second source and transport beamline (IRIS2) for radioactive ions, which will increase operations efficiency and reliability.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ATLAS Hours of Operation with Beam | | | |
| Achieved Operating Hours | 5,672 | N/A | N/A |
| Planned Operating Hours | 5,200 | 5,200 | 5,900 |
| Optimal Hours | 6,600 | 6,600 | 6,600 |
| Percent of Optimal Hours | 86% | 79% | 89% |
| Unscheduled Downtime | 5.5% | N/A | N/A |
| Number of Users | 387 | 360 | 410 |

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| HRIBF Hours of Operation with Beam | | | |
| Achieved Operating Hours | 4,431 | N/A | N/A |
| Planned Operating Hours | 3,800 | 5,000 | 5,200 |
| Optimal Hours | 6,100 | 6,100 | 6,100 |
| Percent of Optimal Hours | 73% | 82% | 85% |
| Unscheduled Downtime | 17.6% | N/A | N/A |
| Number of Users | 257 | 260 | 260 |

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **Other Operations** | **3,350** | **3,832** | **4,253** |

The NRO and USAF will jointly provide $2,200,000 to utilize the 88-Inch Cyclotron for approximately 2,000 hours for their testing program. NP will provide $4,089,000 to utilize it for approximately 3,000 hours for the in-house nuclear physics research program. Funding is also provided for maintenance of the Oak Ridge Electron Accelerator (ORELA) for criticality measurements supported by DOE/NNSA.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **Facility for Rare Isotope Beams** | **—** | **7,000** | **9,000** |

Funds are requested to continue R&D and conceptual design activities aimed at developing FRIB. This facility will enable world-leading research opportunities in nuclear structure, nuclear astrophysics, and fundamental studies, and complement other rare isotope beam research programs at facilities elsewhere in the world.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **Total, Low Energy Nuclear Physics** | **82,279** | **94,618** | **116,816** |

## Explanation of Funding Changes

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| **Research** | |
| ▪ **University Research** | |
| FY 2010 funding is increased to augment experimental capabilities at research universities and levels of personnel needed to support the experimental programs and achieve NSAC performance goals, operate university accelerators, and support non-accelerator initiatives. Funding supports revitalization of university infrastructure and equipment. | +5,166 |
| ▪ **National Laboratory Research** | |
| • National Laboratory User Facility Research funding maintains personnel at levels needed to support the highest priority research efforts and activities at the ATLAS and HRIBF and includes maintaining and implementing scientific instrumentation at the user facilities. | -41 |

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| Other National Laboratory Research funding supports a suite of MIEs according to their planned project profile, maintaining cost and schedule baselines and meeting international commitments. These include GRETINA (-$1,570,000), CUORE (+$2,500,000), nEDM (+$3,400,000), Rare Isotope Beam Science Initiatives (+$4,200,000), and FNPB (-$1,500,000) for which funding is complete in FY 2009. In addition, increased support is provided for laboratory computing, instrumentation, and workforce for enhanced research efforts (+$4,227,000); and Applications of Nuclear Science and Technology is increased (+$1,527,000) to support nuclear science research that is inherent to a broad suite of applications. | +12,784 |
| **Total, National Laboratory Research** | **+12,743** |
| ▪ **Other Research** | |
| SBIR and other funded at levels required proportionate to R&D activities. | -500 |
| **Total, Research** | **+17,409** |
| **Operations** | |
| ▪ User Facility Operations increases for HRIBF (+$1,198,000) and ATLAS (+$839,000) to maintain staff and more effectively operate these two national user facilities, and capital investments increase (+$331,000) to address a backlog of small instrumentation and infrastructure needs. | +2,368 |
| ▪ Other Operations increases to provide needed funding for maintenance of the 88-Inch Cyclotron. | +421 |
| ▪ The increase for the Facility for Rare Isotope Beams reflects additional funds to continue R&D and conceptual design activities. | +2,000 |
| **Total, Operations** | **+4,789** |
| **Total Funding Change, Low Energy Nuclear Physics** | **+22,198** |

## Nuclear Theory

### Funding Schedule by Activity

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Nuclear Theory | | | |
| Theory Research | | | |
| University Research | 13,606 | 14,999 | 15,968 |
| National Laboratory Research | 12,404 | 14,189 | 16,354 |
| Scientific Discovery through Advanced Computing (SciDAC) | 2,304 | 2,777 | 2,773 |
| Total, Theory Research | 28,314 | 31,965 | 35,095 |
| Nuclear Data Activities | 6,097 | 7,411 | 8,324 |
| Total, Nuclear Theory | 34,411 | 39,376 | 43,419 |

## Description

The Nuclear Theory subprogram supports theoretical research at universities and DOE national laboratories with the goal of improving our fundamental understanding of nuclear physics, interpreting the results of experiments carried out under the auspices of the experimental nuclear physics program, and identifying and exploring important new areas of research.

This subprogram addresses all three of nuclear physics' scientific frontiers. A major theme of this subprogram is an understanding of the mechanisms and effects of quark confinement and de-confinement. A quantitative description of these phenomena starting from the fundamental theory of QCD remains one of this subprogram's great intellectual challenges. New theoretical and computational tools are being developed to describe nuclear many-body phenomena, which will likely have important applications in condensed matter physics and in other areas of the physical sciences. Another major research area is nuclear astrophysics, which includes efforts to understand the origins of the elements (as in supernovae) and the consequences that neutrino masses have for nuclear astrophysics and for the current theory of elementary particles and forces.

One area of nuclear theory that has a particularly pressing demand for large dedicated computational resources is that of lattice quantum chromodynamics (LQCD). LCQD calculations are critical for understanding many of the experimental results from RHIC and CEBAF that involve the strong interaction between quarks and gluons. This subprogram provides researchers with adequate access to powerful supercomputers for these studies, such as the high-performance computational facility at the National Energy Research Scientific Computing Center (NERSC) at LBNL, as well as specialized computers at other institutions. In a joint effort started in FY 2006, the Nuclear Theory subprogram and the High Energy Physics (HEP) Theory subprogram initiated the development of large-scale facilities to provide computing capabilities based on community cluster systems. By the end of FY 2009, it is anticipated that this joint HEP/NP initiative will be operating facilities with an aggregate capacity of 18 teraflops; this initiative continues in FY 2010.

The Nuclear Theory subprogram also sponsors the Institute for Nuclear Theory (INT) at the University of Washington, which carries out a range of activities in support of the work of the nuclear physics community. INT includes visiting scientists, research fellows, postdoctoral fellows, graduate students, and several leading nuclear theorists as permanent staff. INT also hosts a series of specialized research programs on specific topics in nuclear theory and related fields that are identified by the research community as being of high priority.

The National Nuclear Data program compiles, evaluates, and disseminates nuclear data for basic research and applications in an on-line data base that is readily accessible and user oriented.

The Nuclear Theory subprogram is strengthened by its interactions with complementary programs overseas, NSF-supported theory efforts, programs supported by the DOE HEP program, Japanese-supported theoretical efforts related to RHIC at the RIKEN Center at Brookhaven National Laboratory, and the Japan-U.S. Theory Institute for Physics with Rare Isotope Nuclei (JUSTIPEN) at RIKEN in Wako, Japan.

**Selected FY 2008 Accomplishments**

- The quark-gluon plasma (QGP), which is studied in experiments at RHIC, appears to behave as an exotic perfect fluid. Recently, string theory methods have been used to calculate some of the fluid parameters of the QGP, such as viscosity and entropy density. This provides a novel application of the work of string theorists to current experimental studies; string theory usually addresses extremely high energies and tiny length scales that are far removed from experiments.
- The prediction of properties of large nuclei starting from the basic interactions between two and three neutrons and protons has long been a goal of nuclear theory. Recent advancement in this effort have been reported by the SciDAC Collaboration Universal Nuclear Energy Density Functional (UNEDF), which is supported by NP, the National Nuclear Security Administration, and the Advanced Scientific Computing Research program; their results include coupled-cluster calculations of the properties of medium-sized nuclei containing up to 40 and 48 neutrons and protons.
- Important progress has been made in the determination of the nuclear forces between neutrons and protons in the nucleus using a lattice formulation of QCD implemented on a supercomputer. In this work, direct QCD predictions for the nuclear forces between strongly interacting particles known as mesons (quark-antiquark bound states) were studied. This preliminary study of mesons will be followed by supercomputer-based studies of the true nuclear force between neutrons and protons, as is observed within nuclei.

## Detailed Justification

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| **Theory Research** | **28,314** | **31,965** | **35,095** |
| ▪ **University Research** | **13,606** | **14,999** | **15,968** |

The Nuclear Theory program supports the research of approximately 150 academic scientists and 110 graduate students through 65 research grants at 43 universities in 28 states and the District of Columbia. The funding will support the necessary level of theoretical effort needed for interpretation of experimental results obtained at the NP facilities, the training of next-generation nuclear theorists, and will allow the start of several new research grants in specific growth areas of nuclear theory. The overall nuclear theory effort is aligned with the experimental program through the program performance milestones established by NSAC.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| ▪ **National Laboratory Research** | **12,404** | **14,189** | **16,354** |

Research programs are supported at seven national laboratories (ANL, BNL, LANL, LBNL, LLNL, ORNL, and TJNAF) to achieve NSAC performance goals and interpret experimental results. The nuclear theory research at a given laboratory provides support to the experimental programs at that laboratory, or takes advantage of some unique facilities or programs at that laboratory. The larger size and diversity of the national laboratory groups make them particularly good sites for the training of nuclear theory postdoctoral associates. In FY 2009, the laboratory groups will be evaluated based on the significance of their accomplishments and future program, scientific leadership, creativity and productivity of the personnel, and the overall cost-effectiveness of the group. Results of the review will influence future budget decisions.

Support continues for the Excited Baryon Analysis Center (EBAC) at TJNAF. In FY 2010 continued investments in LQCD computer capabilities will be supported in a joint effort with High Energy Physics.

| | | | |
|---|---|---|---|
| ▪ **Scientific Discovery through Advanced Computing (SciDAC)** | **2,304** | **2,777** | **2,773** |

SciDAC is a collaborative program that partners scientists and computer experts in research teams to address major scientific challenges that require supercomputer facilities at the current technological limits. Supported SciDAC efforts include nuclear astrophysics, grid computing, QCD, low energy nuclear structure and nuclear reaction theory and advanced accelerator design. In FY 2010, NP partners with ASCR, HEP, and NNSA to fund these efforts.

| | | | |
|---|---|---|---|
| **Nuclear Data Activities** | **6,097** | **7,411** | **8,324** |

This effort involves the work of several national laboratories and universities and is guided by the DOE-managed National Nuclear Data Center (NNDC) at BNL. Funding provides support for a viable effort and addresses long-standing issues in staffing shortages. The NNDC relies on the U.S. Nuclear Data Network (USNDN), a network of DOE-supported individual nuclear data professionals located in universities and national laboratories that perform assessment as well as developing modern network dissemination capabilities. The NNDC participates in the International Data Committee of the International Atomic Energy Agency.

Funding is also provided to support initiatives in Applications of Nuclear Science and Technology, including efforts relevant to nuclear fuel cycle.

| | | | |
|---|---|---|---|
| **Total, Nuclear Theory** | **34,411** | **39,376** | **43,419** |

## Explanation of Funding Changes

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| **Theory Research** | |
| ▪ **University Research** | |
| FY 2010 provides increased support for personnel to focus on the theoretical understanding of the research that was identified in the NSAC report on performance measures and milestones and to implement recommendations from the NSAC Subcommittee on Nuclear Theory. | +969 |
| ▪ **National Laboratory Research** | |
| FY 2010 funding provides increased support for theoretical efforts needed to achieve the scientific goals of the Nuclear Physics program, including the continuation of the LQCD initiative with HEP. | +2,165 |
| ▪ **Scientific Discovery through Advanced Computing (SciDAC)** | |
| FY 2010 funding allows for continued support in the most promising areas for progress in nuclear physics with terascale computing capabilities. | -4 |
| **Total, Theory Research** | +3,130 |
| **Nuclear Data Activities** | |
| FY 2010 funding increases are needed to support a viable effort in Nuclear Data related activities (+$246,000), and to expand Applications of Nuclear Science and Technology (+$667,000). | +913 |
| **Total Funding Change, Nuclear Theory** | **+4,043** |

## Isotope Development and Production for Research and Applications

## Funding Schedule by Activity

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Isotope Development and Production for Research and Applications | | | |
| Research | | | |
| National Laboratory Research | — | 4,860 | 3,000 |
| Other Research[a] | — | 200 | 90 |
| Total, Research | — | 5,060 | 3,090 |
| Operations | | | |
| University Operations | — | 200 | 250 |
| Isotope Production Facility Operations | — | 2,790 | 1,068 |
| Brookhaven Linear Isotope Producer Operations | — | 770 | 600 |
| National Isotope Data Center (NIDC) | — | 1,024 | 1,440 |
| Other National Laboratory Operations | — | 15,056 | 12,752 |
| Total, Operations | — | 19,840 | 16,110 |
| Total, Isotope Development and Production for Research and Applications | —[b] | 24,900 | 19,200 |

### Description

In FY 2009, this new subprogram was transferred to the Office of Science from the Office of Nuclear Energy. The FY 2010 budget request for Isotope Development and Production for Research and Applications is reflective of the rest of the Nuclear Physics budget with a focus on Research and Operations. This subprogram continues to re-establish the goal of supporting research and development and production of research isotopes. To achieve this goal, the Isotope Development and Production for Research and Applications subprogram provides facilities and capabilities for the production of research and commercial stable and radioactive isotopes, scientific and technical staff associated with general isotope research and production, and a supply of critical isotopes to address the needs of the Nation. The immediate benefits of a viable research and development component of the Isotope Development and Production for Research and Applications subprogram include the reduced dependence on foreign supplies, new scientific applications for isotopes not currently supplied, and the ability to meet both present and future research needs for isotopes.

Stable and radioactive isotopes are vital to the mission of many Federal agencies and play a crucial role in basic research, medicine, industry, and homeland defense. Isotopes are produced for the National Institutes of Health and their grantees, National Institute of Standards and Technology, Environmental Protection Agency, Department of Agriculture, National Nuclear Security Administration, Department of

[a] This activity includes $125,000 for SBIR and $15,000 for STTR in FY 2009 and $80,000 for SBIR and $10,000 for STTR in FY 2010.
[b] Funding prior to FY 2009 is provided under the Nuclear Energy, Radiological Facilities Management program.

Homeland Security, other DOE Office of Science programs, and other Federal agencies. The subprogram also supports research related to the development of advanced isotope production techniques.

Isotopes are used to improve the accuracy and effectiveness of medical diagnoses and therapy, enhance national security, improve the efficiency of industrial processes, and provide precise measurement and investigative tools for materials, biomedical, environmental, archeological, and other research. Some examples are: strontium-82 used for heart imaging; germanium-68 used for calibrating the growing numbers of imaging scanners; arsenic-73 used as a tracer for environmental research, and nickel-63 used as a component in gas sensing devices or helium-3 as a component in neutron-detectors both used for applications in homeland defense. Some isotopes are critical resources to very diverse operations in industry and science and have a profound impact on the Nation's economy and national security. Californium-252, for example, is used in a wide array of applications for medicine, homeland defense, and energy security.

The consequences of shortages of radioactive and stable isotopes needed for research, medicine, homeland security, and industrial applications can be extremely serious ranging from the inability to treat cancer to the failure of detecting terrorist threats. NP sponsored a workshop in August 2008 with stakeholders from the research community, industry and Federal agencies to identify those isotopes critical to meeting the Nation's present and future needs and the role of the Isotope Development and Production for Research and Applications subprogram in fulfilling these needs. NSAC was charged in August 2008 to develop a prioritized list of research topics using isotopes and to develop a long-range strategic plan for stable and radioactive isotope production. A final report will be issued in summer of 2009. NP has also established a working group with the National Institutes of Health to address the recommendations of the recent National Academies report, *Advancing Nuclear Medicine through Innovation*[a], which identified several areas in isotope production warranting attention. Finally, NP has facilitated the formation of a federal working group on He-3 supply, involving staff from NP, NNSA, the Department of Homeland Security, and the Department of Defense.

Isotopes are made available by using the Department's unique facilities, the Brookhaven Linear Isotope Producer (BLIP) at BNL and the Isotope Production Facility (IPF) at LANL, of which the subprogram has stewardship responsibilities. The subprogram also produces isotopes at the reactors at Oak Ridge and Idaho National Laboratories. In FY 2009, the subprogram will explore production capabilities at university and other laboratory facilities in order to make high priority isotopes more available. Hot cell facilities at Brookhaven, Oak Ridge, and Los Alamos National Laboratories are used and maintained by the program for processing and handling irradiated materials and purified products. Facilities at other national laboratories are used as needed, such as for processing and packaging strontium-90 from the Pacific Northwest National Laboratory. Over 50 researchers and staff at the national laboratories are supported to provide the technical expertise in research, development, and transportation of isotopes. Research and development includes target fabrication, enhanced processing techniques, radiochemistry, material conversions, and other related services.

The Isotope Development and Production for Research and Applications subprogram, which operates under a revolving fund as established by the FY 1990 Energy and Water Development Appropriations Act (Public Law 101–101) as modified by Public Law 103–316, maintains its financial viability by utilizing a combination of Congressional appropriations and revenues from the sale of isotopes and services. These resources are used to maintain the staff, facilities, and capabilities at user-ready levels

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[a] http://dels.nas.edu/dels/rpt_briefs/advancing_nuclear_medicine.pdf

and to support peer-reviewed research and development activities related to the production of isotopes. Commercial isotopes are priced at full cost. Research isotopes are priced to provide reasonable compensation to the government while encouraging research. Investments in new capabilities are made to meet the growing demands of the Nation and foster research in the applications that will support the health and welfare of the public.

The subprogram is benefitting substantially from Recovery Act funding, which complements the FY 2010 Budget Request. Support under the Recovery Act was provided for an initiative to support R&D on the development of alternative and innovative approaches for the development and production of critical isotopes. Recovery Act support was also provided for the utilization of isotope production facilities, which included additional operations for the production of isotopes, one-time investments to improve the efficiency or provide new capabilities for the production of isotopes, and opportunities to establish production capabilities at new production sites.

### FY 2008 Selected Accomplishments

- Researchers at ORNL successfully developed the production of high specific activity lutetium-177 used in peptide radio-labeling. Lutetium-177 emits a low beta energy, which reduces radiation side effects and produces a tissue-penetration range appropriate for smaller tumors and colon, bone, liver, and lung cancer. Samples of high specific activity lutetium-177 have been distributed to research institutions worldwide for testing.
- In a collaborative effort, barium-131 and barium-140 were produced at the High Flux Isotope Reactor (HFIR) and at the BR2 reactor at Mol, Belgium, respectively. Both irradiations enabled researchers to assess yields, burn up, and other reactor production parameters. Cesium-131, the daughter isotope of barium-131, is an alternative for the manufacture of seed implants for prostate cancer therapy. The daughter of barium-140, lanthanum-140, is a high-energy gamma emitter that is of interest for a potentially new imaging technology.
- Researchers developed the production of yttrium-86 at BNL which resulted in high yields, but less purity than desired. Yttrrium-86 is a short-lived isotope emitting positrons, which can be used for positron emission tomography (PET) imaging prior to cancer immunotherapy with yttrium-90. Yttrium-86 labeled tumor-seeking monoclonal antibodies can be used for evaluating effective tumor uptake and radiation dose. Experiments to improve the product purity will be conducted in FY 2009 using low-energy protons.
- NP negotiated a partnership with industry to support continued production of californium-252, critical to many applications in industry, homeland defense, and research.

## Detailed Justification

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| **Research** | **—** | **5,060** | **3,090** |

Research is supported to identify, design, and optimize production targets and separation methods. Examples for planned research includes: the need for positron-emitting radionuclides to support the rapidly growing area of medical imaging using PET; the development of isotopes that support medical research to be used to diagnose diseases spread through acts of bioterrorism as well as their treatment; the development of production methods for alpha-emitting radionuclides that exhibit great potentials in

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |

disease treatment; the development and use of research isotopes for various biomedical applications; and the need for alternative isotope supplies for national security applications and advanced power sources. Priorities in research isotope production are informed by guidance from NSAC. All R&D activities are peer reviewed. In addition, Recovery Act funding continues to support R&D in alternative isotope production techniques, which complements these research efforts in FY 2010.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **National Laboratory Research** | **—** | **4,860** | **3,000** |

Support is provided for scientists at the national laboratories (BNL, LANL, ORNL, INL, PNNL) to perform peer-reviewed experimental research on targets, separation technology maturation and development of isotope production techniques, and for the production of research isotopes at affordable rates. R&D activities utilize the reactors at INL and ORNL and the accelerators at LANL and BNL. Researchers provide unique expertise and facilities for data analysis.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **Other Research** | **—** | **200** | **90** |

This activity includes $125,000 for SBIR and $15,000 for STTR in FY 2009 and $80,000 for SBIR and $10,000 for STTR in FY 2010.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **Operations** | **—** | **19,840** | **16,110** |

Operations funding is provided to support the core facility scientists and engineers and to effectively operate the Isotope Development and Production for Research and Applications facilities, including facility maintenance and investments in new capabilities. In addition, Recovery Act funding continues to support enhanced utilization of isotope facilities, including additional isotope production and one-time investments in infrastructure and new capabilities.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **University Operations** | **—** | **200** | **250** |

Funding is provided to academic institutions with reactors and cyclotrons for the production and development of isotopes to enhance the subprogram's isotope portfolio.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **Isotope Production Facility (IPF) Operations** | **—** | **2,790** | **1,068** |

The IPF operates in a parallel-mode in accordance with the Los Alamos Neutron Science Center (LANSCE) of about 22 weeks in FY 2010. The IPF produces isotopes such as germanium-68, strontium-82, and arsenic-73. Support is provided in FY 2010 for the operation, maintenance, and improvement of the IPF, including radiological monitoring, facility inspections, and records management. Upgrades at IPF, including one-time costs for replacement of the control and target loading systems, were funded in FY 2009.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **Brookhaven Linear Isotope Producer (BLIP) Operations** | **—** | **770** | **600** |

BLIP operates in parallel mode in accordance with the RHIC operating schedule and additionally in dedicated mode to meet customer needs. BLIP produces isotopes such as copper-67, germanium-68 and strontium-82. Support is provided in FY 2010 for the operation, maintenance, and improvement of BLIP, including radiological monitoring, facility inspections, and records management. Several one-time equipment upgrades were funded in FY 2009.

(dollars in thousands)

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **National Isotope Data Center (NIDC)** | **—** | **1,024** | **1,440** |

The National Isotope Data Center (NIDC) is a management information center for all national laboratories and universities in the subprogram's portfolio producing and distributing isotopes. The NIDC coordinates and integrates multi-laboratory isotope production schedules, maintains isotope inventory balances and transportation container inventory and certifications, and conducts various outreach and societal activities. The business office within the NIDC is located at ORNL and coordinates all customer data such as official quotations, account balances, shipping schedules and delivery tracking, and other pertinent information. Funding is provided to support the staff located throughout the national laboratory complex that are needed to oversee these activities.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **Other National Laboratory Operations** | **—** | **15,056** | **12,752** |

The Isotope program makes intensive use of hot cell facilities at the three main isotope production sites: BNL, LANL, and ORNL. Funding is provided to each of these facilities for the technical expertise and hot cell facilities in order to support the handling and processing of radioactive materials. Support is provided in FY 2010 for the Chemical and Material Laboratories at ORNL that is used for processing stable isotopes, as well as activities including radiological monitoring, facility inspections, records management, the certification of isotope shipping casks, and other related expenses. The one-time costs for modernization of the train control system to meet current facility requirements at LANL and relocation of sub-category-3 level quantities of radioisotope materials at ORNL were funded in FY 2009.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **Total, Isotope Development and Production for Research and Applications** | **—** | **24,900** | **19,200** |

## Explanation of Funding Changes

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| **Research** | |
| Reduced funding for research and development reflects the increased congressional funding for this activity in FY 2009. These activities are guided by priorities in research isotope production developed by NSAC and are complemented by Recovery Act funding for R&D on alternative isotope production techniques. | -1,970 |
| **Operations** | |
| ▪ **University Operations** | |
| Increased funding enhances capability, staff, and expertise for cost-efficient operations to develop and produce isotopes. | +50 |

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| ▪ **Isotope Production Facility (IPF) Operations** | |
| The reduced funding in FY 2010 reflects completion in FY 2009 of upgrades, including a one-time investment to address infrastructure needs at the IPF in the control system and target loading system. | -1,722 |
| ▪ **Brookhaven Linear Isotope Producer (BLIP) Operations** | |
| The reduced funding in FY 2010 reflects completion in FY 2009 of one-time investments for the replacement of the acid fume scrubber system, upgrades to the BLIP beam, and the installation of a crane/rail system for manipulator repairs. | -170 |
| ▪ **National Isotope Data Center (NIDC)** | |
| An increase is provided for the NIDC to meet its mission to coordinate isotope activities and customer data. | + 416 |
| ▪ **Other National Laboratory Operations** | |
| The reduced funding in FY 2010 reflects completion of upgrades in FY 2009, including one-time investments for modernization of the train control system at LANL and relocation of sub-category-3 level quantities of radioisotope materials at ORNL. | -2,304 |
| **Total, Operations** | **-3,730** |
| **Total Funding Change, Isotope Development and Production for Research and Applications** | **-5,700** |

## Construction

### Funding Schedule by Activity

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Construction | | | |
| 07-SC-02, Electron Beam Ion Source, BNL | 4,162 | 2,438 | — |
| 06-SC-01, 12 GeV CEBAF Upgrade (PED/Construction), TJNAF | 13,377 | 28,623 | 22,000 |
| Total, Construction | 17,539 | 31,061 | 22,000 |

### Description

This subprogram provides for Construction and Project Engineering and Design (PED) that is needed to meet overall objectives of the Nuclear Physics program.

### Detailed Justification

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| **07-SC-02, Electron Beam Ion Source, BNL** | **4,162** | **2,438** | — |

The Electron Beam Ion Source (EBIS) project to replace the high maintenance tandems as the RHIC pre-injector, leading to more cost effective operations and new research capabilities, will be completed in FY 2010 with funding appropriated in previous years. This project is jointly supported between NP and NASA.

| | | | |
|---|---|---|---|
| **06-SC-01, 12 GeV CEBAF Upgrade (PED/Construction), TJNAF** | **13,377** | **28,623** | **22,000** |

In FY 2010, funding is requested to continue construction of the 12 GeV CEBAF Upgrade. The upgrade was identified in the 2007 NSAC Long-Range Plan as the highest priority for the U.S. Nuclear Physics program and is a near-term priority in the SC 20-Year Facilities Outlook. The upgrade will enable scientists to address one of the mysteries of modern physics—the mechanism of quark confinement. In FY 2009, funding for PED activities is completed. In addition to the funding reflected above, the project also received Recovery Act funding of $65,000,000 in FY 2009 which advances a portion of the original FY 2010 and FY 2011 planned funding.

| | | | |
|---|---|---|---|
| **Total, Construction** | **17,539** | **31,061** | **22,000** |

### Explanation of Funding Changes

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| **07-SC-02, Electron Beam Ion Source, BNL** | |
| The last year of funding for this project was FY 2009. | -2,438 |

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| **06-SC-01, 12 GeV CEBAF Upgrade (PED/Construction), TJNAF** | |
| Support is provided to continue construction of the 12 GeV CEBAF Upgrade according to the planned profile and taking into account advanced funding provided under the Recovery Act. | -6,623 |
| **Total Funding Change, Construction** | **-9,061** |

## Supporting Information

## Operating Expenses, Capital Equipment and Construction Summary

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Operating Expenses | 366,991 | 435,738 | 467,849 |
| Capital Equipment | 26,574 | 38,126 | 53,523 |
| General Plant Projects | 7,736 | 1,000 | 2,000 |
| Accelerator Improvement Projects | 4,831 | 6,155 | 6,628 |
| Construction | 17,539 | 31,061 | 22,000 |
| Total, Nuclear Physics | 423,671 | 512,080 | 552,000 |

## Funding Summary

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Research | | | |
| National Laboratory Research [a] | 75,973 | 89,654 | 102,353 |
| University Research [a] | 63,794 | 69,516 | 78,467 |
| Other Research [b] | 4,319 | 14,134 | 15,841 |
| Total Research | 144,086 | 173,304 | 196,661 |
| Scientific User Facilities Operations | 234,266 | 258,648 | 277,232 |
| Other Facility Operations | 5,350 | 23,672 | 20,363 |
| Major Items of Equipment | 13,147 | 13,651 | 20,030 |
| Construction Projects | 17,539 | 31,061 | 22,000 |
| Other [c] | 9,283 | 11,744 | 15,714 |
| Total Nuclear Physics | 423,671 | 512,080 | 552,000 |

## Scientific User Facilities Operations and Research

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| RHIC (BNL) | | | |
| Operations | 137,041 | 148,859 | 160,180 |
| Facility Research/MIEs | 9,819 | 10,377 | 8,982 |
| Total RHIC | 146,860 | 159,236 | 169,162 |

[a] Funding for SciDAC and Nuclear Data activities is split between National Laboratory Research and University Research.
[b] Funding shown in Other Research for Accelerator R&D and Generic Rare Isotope Beam R&D will be distributed to National Laboratories and Universities.
[c] Other includes BNL GPE and FRIB Other Project Costs (R&D and Conceptual Design).

| (dollars in thousands) | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| CEBAF (TJNAF) | | | |
| Operations | 71,740 | 78,959 | 83,854 |
| Facility Research/MIEs | 9,952 | 10,229 | 11,190 |
| Total CEBAF | 81,692 | 89,188 | 95,044 |
| | | | |
| HRIBF (ORNL) | | | |
| Operations | 13,081 | 15,650 | 16,645 |
| Facility Research/MIEs | 5,272 | 4,327 | 4,121 |
| Total HRIBF | 18,353 | 19,977 | 20,766 |
| | | | |
| ATLAS (ANL) | | | |
| Operations | 12,404 | 15,180 | 16,553 |
| Facility Research/MIEs | 5,730 | 4,700 | 4,865 |
| Total ATLAS | 18,134 | 19,880 | 21,418 |
| | | | |
| Total Scientific User Facilities | | | |
| Operations | 234,266 | 258,648 | 277,232 |
| Facility Research/MIEs | 30,773 | 29,633 | 29,158 |
| Total Scientific User Facilities | 265,039 | 288,281 | 306,390 |

## Total Facility Hours and Users

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| Hours of Operation with Beam | | | |
| RHIC (BNL) | | | |
| Optimal Hours | 4,100 | 4,100 | 4,100 |
| Planned Operating Hours | 3,192 | 2,480 | 3,720 |
| Achieved Operating Hours | 2,566 | N/A | N/A |
| Unscheduled Downtime | 16.7% | N/A | N/A |
| Number of Users | 1,200 | 1,200 | 1,200 |
| CEBAF (TJNAF) | | | |
| Optimal Hours | 5,600 | 5,980 | 5,980 |
| Planned Operating Hours | 3,500 | 4,965 | 5,110 |
| Achieved Operating Hours | 3,914 | N/A | N/A |
| Unscheduled Downtime | 8.0% | N/A | N/A |
| Number of Users | 1,313 | 1,350 | 1,390 |

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| HRIBF (ORNL) | | | |
| Optimal Hours | 6,100 | 6,100 | 6,100 |
| Planned Operating Hours | 3,800 | 5,000 | 5,200 |
| Achieved Operating Hours | 4,431 | N/A | N/A |
| Unscheduled Downtime | 17.6% | N/A | N/A |
| Number of Users | 257 | 260 | 260 |
| ATLAS (ANL) | | | |
| Optimal Hours | 6,600 | 6,600 | 6,600 |
| Planned Operating Hours | 5,200 | 5,200 | 5,900 |
| Achieved Operating Hours | 5,672 | N/A | N/A |
| Unscheduled Downtime | 5.5% | N/A | N/A |
| Number of Users | 387 | 360 | 410 |
| Total Facilities | | | |
| Optimal Hours | 22,400 | 22,780 | 22,780 |
| Planned Operating Hours | 15,692 | 17,645 | 19,930 |
| Achieved Operating Hours | 16,583 | N/A | N/A |
| Unscheduled Downtime | 11.4% | <20% | <20% |
| Total Number of Users | 3,157 | 3,170 | 3,260 |

## Major Items of Equipment

(dollars in thousands)

| | Prior Years | FY 2008 | FY 2009 | FY 2009 Additional Approp. | FY 2010 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| **Heavy Ion Nuclear Physics** | | | | | | | |
| Heavy Ion LHC Experiments, LBNL | | | | | | | |
| TEC | 1,000 | 2,000 | 4,000 | — | 5,000 | 1,205 | 13,205 |
| OPC | 295 | — | — | — | — | — | 295 |
| TPC | 1,295 | 2,000 | 4,000 | — | 5,000 | 1,205 | 13,500 |
| PHENIX Silicon Vertex Tracker, BNL | | | | | | | |
| TEC/TPC | 1,599 | 2,000 | 851 | 250 | — | — | 4,700 |

(dollars in thousands)

| | Prior Years | FY 2008 | FY 2009 | FY 2009 Additional Approp. | FY 2010 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| PHENIX Forward Vertex Detector, BNL | | | | | | | |
| TEC/TPC | — | 700 | 2,200 | 2,000 | — | — | 4,900 |
| PHENIX Nose Cone Calorimeter, BNL[a] | | | | | | | |
| TEC/TPC | — | 200 | — | — | — | — | N/A |
| STAR Heavy Flavor Tracker, BNL | | | | | | | |
| TEC | — | — | — | — | 1,400 | TBD | TBD |
| OPC | — | — | — | — | — | TBD | TBD |
| TPC | — | — | — | — | 1,400 | TBD | 11,000-15,000 |
| **Low Energy Nuclear Physics** | | | | | | | |
| GRETINA, Gamma-Ray Detector, LBNL | | | | | | | |
| TEC | 10,400 | 4,170 | 2,000 | — | 430 | — | 17,000 |
| OPC | 1,200 | — | 300 | — | 300 | — | 1,800 |
| TPC | 11,600 | 4,170 | 2,300 | — | 730 | — | 18,800 |
| Fundamental Neutron Physics Beamline, ORNL | | | | | | | |
| TEC | 5,600 | 1,500 | 1,500 | 600 | — | — | 9,200 |
| OPC | 88 | — | — | — | — | — | 88 |
| TPC | 5,688 | 1,500 | 1,500 | 600 | — | — | 9,288 |
| Neutron Electric Dipole Moment (nEDM), LANL | | | | | | | |
| TEC | 770 | 2,177 | 1,100 | — | 4,500 | TBD | TBD |
| OPC | 430 | 323 | — | — | — | TBD | TBD |
| TPC | 1,200 | 2,500 | 1,100 | — | 4,500 | TBD | 17,600-19,000 |
| Cryogenic Underground Observatory for Rare Events (CUORE), LBNL | | | | | | | |
| TEC | — | 400 | 2,000 | — | 4,500 | TBD | TBD |
| OPC | 464 | 300 | — | — | — | TBD | TBD |
| TPC | 464 | 700 | 2,000 | — | 4,500 | TBD | 8,000-10,000 |

[a] Based on scientific merit review, and in the context of constrained resources, it was decided to cancel this MIE.

(dollars in thousands)

| | Prior Years | FY 2008 | FY 2009 | FY 2009 Additional Approp. | FY 2010 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| Rare Isotope Beam Science Initiatives | | | | | | | |
| TEC | — | — | — | — | 4,200 | TBD | TBD |
| OPC | — | — | — | — | — | TBD | TBD |
| TPC | — | — | — | — | 4,200 | TBD | 2,000-20,000 |
| Total MIEs | | | | | | | |
| TEC | | 13,147 | 13,651 | 2,850 | 20,030 | | |
| OPC | | 623 | 300 | — | 300 | | |
| TPC | | 13,770 | 13,951 | 2,850 | 20,330 | | |

### Heavy Ion Nuclear Physics MIEs

*Heavy Ion LHC Experiment (ALICE EMCal), LBNL:* This MIE fabricates a large electromagnetic calorimeter (EMCal) for the ALICE experiment at the LHC, and is a joint project with France and Italy. It received CD-2/3 approval in February 2008 and is scheduled to finish in FY 2011.

*PHENIX Silicon Vertex Tracker (VTX), BNL:* This MIE fabricates a barrel of silicon pixel and strip detectors for high-precision tracking and vertexing and is a joint project with Japan. The TPC was baselined at a technical, cost, schedule, and management review in May 2006 and the project is scheduled to finish in FY 2010. The project received its final funding of $250,000 under the Recovery Act.

*PHENIX Forward Vertex Detector (FVTX), BNL:* This MIE fabricates two silicon endcaps to extend the VTX tracking and vertexing capabilities. The TPC was baselined at a technical, cost, schedule, and management review in November 2007. The project is scheduled to finish in FY2011. The project received its final funding of $2,000,000 under the Recovery Act.

*PHENIX Nose Cone Calorimeter (NCC), BNL:* Based on scientific merit review, and in the context of constrained resources, it was decided to cancel this MIE. Funds that had been allocated to the project in FY 2008 have been redirected to other high priority instrumentation needs at BNL.

*STAR Heavy Flavor Tracker (HFT), BNL:* This MIE will fabricate a high-precision tracking and vertexing device based on ultra-thin silicon pixel and pad detectors in the STAR detector. It received CD-0 approval in February 2009 and is scheduled for initiation in FY 2010 and completion in FY 2014.

### Low Energy Nuclear Physics MIEs

*GRETINA Gamma-Ray Detector, LBNL:* This MIE fabricates an array of highly-segmented germanium crystals for gamma ray detection. It received CD-2/3 approval in October 2007 and is scheduled to finish in FY 2011. This detector will be shared by the Nation's low energy accelerator facilities operated by both DOE and NSF.

*Fundamental Neutron Physics Beamline (FNPB), ORNL:* This MIE fabricates two beam lines at the SNS to deliver record peak currents of cold and ultra-cold neutrons for studies of fundamental neutron properties. It received CD-4a approval in September 2008 and is scheduled to finish in FY 2010. The project received its final funding of $600,000 under the Recovery Act.

*Neutron Electric Dipole Moment (nEDM), LANL:* This MIE fabricates a cryogenic apparatus to measure the neutron electric dipole moment using ultra-cold neutrons from the FNPB. It received CD-1 approval in February 2007 and is scheduled to finish in FY 2015. The NSF expects to contribute $7.3 million to this project.

*Cryogenic Underground Observatory for Rare Events (CUORE), LBNL:* This MIE fabricates the U.S. contribution to the Italian-led CUORE experiment to measure fundamental neutrino properties. It received CD-1 approval in February 2008 and is scheduled to finish in FY 2013.
The NSF expects to contribute $1.3 million to this project.

*Rare Isotope Beam Science Initiatives:* These initiatives consist of one or more MIEs to fabricate instrumentation creating forefront science opportunities at leading rare isotope beam facilities around the world. They received CD-0 approval in February 2009 and are scheduled for initiation in FY 2010 and completion between FY 2012 and FY 2017. The projects will be selected following peer review of solicited proposals.

## Construction Projects

(dollars in thousands)

| | Prior Years | FY 2008 | FY 2009 | FY 2009 Additional Approp. | FY 2010 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| 12 GeV CEBAF Upgrade, TJNAF | | | | | | | |
| TEC | 7,500 | 13,377 | 28,623 | 65,000 | 22,000 | 151,000 | 287,500 |
| OPC | 9,500 | 1,000 | — | — | — | 12,000 | 22,500 |
| TPC | 17,000 | 14,377 | 28,623 | 65,000 | 22,000 | 163,000 | 310,000 |
| Electron Beam Ion Source, BNL | | | | | | | |
| TEC | 7,100 | 4,162 | 2,438 | — | — | — | 13,700 |
| OPC | 800 | 100 | 200 | — | — | — | 1,100 |
| TPC | 7,900 | 4,262 | 2,638 | — | — | — | 14,800 |
| Total Construction | | | | | | | |
| TEC | | 17,539 | 31,061 | 65,000 | 22,000 | | |
| OPC | | 1,100 | 200 | — | — | | |
| TPC | | 18,639 | 31,261 | 65,000 | 22,000 | | |

## Scientific Employment

| | (estimated) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| # University Grants | 184 | 190 | 200 |
| Average Size per year | $310,000 | $335,000 | $345,000 |
| # Laboratory Projects | 28 | 33 | 33 |
| # Permanent Ph.Ds | 733 | 698 | 720 |
| # Postdoctoral Associates | 365 | 342 | 390 |
| # Graduate Students | 493 | 490 | 510 |
| # Ph.D.s awarded | 89 | 80 | 80 |

## 06-SC-01, 12 GeV CEBAF Upgrade, Thomas Jefferson National Accelerator Facility
## Newport News, Virginia
## Project Data Sheet is for PED/Construction

### 1. Significant Changes

This Project Data Sheet (PDS) is an update of the FY 2009 PDS.

The most recent DOE O 413.3A approved Critical Decision (CD) is CD-3, Approve Start of Construction, which was signed on September 15, 2008, with a Total Project Cost (TPC) of $310,000,000. Construction was authorized to begin under the FY 2009 Continuing Resolution at FY 2008 funding levels. In March 2009, the project received funding from the American Recovery and Reinvestment Act of 2009 (ARRA) that advances a portion of future FY 2010 and FY 2011 appropriations. The funding is anticipated to reduce project risks. There have been no changes in project scope, cost, or schedule since the project was baselined. There is one high risk and three moderate risks associated with this project, each with a mitigation plan to achieve successful completion. A Federal Project Director (FPD) with certification Level III was assigned to this project as required.

### 2. Design, Construction, and D&D Schedule[a]

(fiscal quarter or date)

| | CD-0 | CD-1 | PED Complete | CD-2 | CD-3 | CD-4 | D&D Start | D&D Complete |
|---|---|---|---|---|---|---|---|---|
| FY 2007 | 03/31/2004 | 1Q 2007 | 4Q 2009 | 4Q 2007 | 4Q 2008 | 1Q 2014 | N/A | N/A |
| FY 2008 | 03/31/2004 | 2/14/2006[a] | 4Q 2009 | 4Q 2007 | 4Q 2008 | 1Q 2015 | N/A | N/A |
| FY 2009 | 03/31/2004 | 2/14/2006 | 4Q 2009 | 11/09/2007 | 4Q 2008 | 3Q 2015 | N/A | N/A |
| FY 2010 | 03/31/2004 | 2/14/2006 | 4Q 2009 | 11/09/2007 | 09/15/2008 | 3Q 2015 | N/A | N/A |

CD-0 – Approve Mission Need
CD-1 – Approve Alternative Selection and Cost Range
CD-2 – Approve Performance Baseline
CD-3 – Approve Start of Construction
CD-4 – Approve Start of Operations or Project Closeout D&D Start – Start of Demolition & Decontamination (D&D) work
D&D Complete –Completion of D&D work

[a] CD-1 was approved on 2/14/2006. Engineering and design activities started in 4Q FY 2006 after Congress approved the Department of Energy's request to reprogram $500,000 within the FY 2006 funding for Nuclear Physics, per direction contained in H.Rpt 109–275.

## 3. Baseline and Validation Status

(dollars in thousands)

| | TEC, PED | TEC, Construction | TEC, Total | OPC Except D&D | OPC, D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2007 | 21,000 | TBD | TBD | 11,000 | TBD | TBD | TBD |
| FY 2008 | 21,000 | TBD | TBD | 10,500 | TBD | TBD | TBD |
| FY 2009 | 21,000 | 266,500 | 287,500 | 22,500 | N/A | 22,500 | 310,000 |
| FY 2010 | 21,000 | 266,500 | 287,500 | 22,500 | N/A | 22,500 | 310,000[a] |

## 4. Project Description, Justification, and Scope

The Continuous Electron Beam Accelerator Facility (CEBAF) at the Thomas Jefferson National Accelerator Facility, or Jefferson Laboratory, is today the world-leading facility in the experimental study of hadronic matter. An energy upgrade of CEBAF has been identified by the nuclear science community as a compelling scientific opportunity that should be pursued. In particular, the Nuclear Science Advisory Committee (NSAC) stated in the 1996 Long Range Plan that "…the community looks forward to future increases in CEBAF's energy, and to the scientific opportunities that would bring." In the 2007 Long Range Plan, NSAC concluded that completion of the 12 GeV CEBAF Upgrade project was the highest priority for the Nation's nuclear science program.

- The 12 GeV CEBAF Upgrade directly supports the Nuclear Physics mission and addresses the objective to measure properties of the proton, neutron, and simple nuclei for comparison with theoretical calculations to provide an improved quantitative understanding of their quark substructure. The upgrade is identified as a near-term priority in the Office of Science Twenty-Year Outlook.

The scope of the project includes upgrading the electron energy capability of the main accelerator from 6 GeV to 12 GeV, building a new experimental hall (Hall D) and associated beam-line, and enhancing the capabilities of the existing experimental halls to support the most compelling nuclear physics research.

Key Performance Parameters to achieve CD-4, *Approve Start of Operations or Project Closeout*, are phased around the accelerator and conventional facilities (CD-4A) and the experimental equipment in Halls B, C, and D (CD-4B). The deliverables defining completion are identified in the Project Execution Plan and have not changed since CD-2. Mitigation plans exist to help ensure that the one high risk associated with the breadth of the vendor pool for the cyrogenics work required and three moderate risks associated with the unforeseen technical problems with the superconducting magnets in two experimental Halls and the fabrication of the Silicon Vertex Tracker will not impact the planned completion dates.

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[a] The Governor of Virginia signed House Bill 1600, the appropriation bill amending the 2008-2010 biennial budget for the Commonwealth of Virginia on March 30, 2009, which provided "$6,000,000 for Jefferson Science Associates, LLC to leverage a federal investment of $310 million for an upgrade of the Jefferson Lab's research facilities, which will maintain its leadership in the study of nuclear physics and secure the benefits of such a facility for the Commonwealth." This funding will be paid in $500,000 monthly increments beginning in July 2009. It is anticipated that this funding will reduce project cost risks and schedule risks and help ensure timely completion of the project. The SC Office of Project Assessment's annual review planned for September 21, 2009, will evaluate any adjustments to the federal government's share of the TPC as a result of the funding from the Commonwealth of Virginia.

The project is being conducted in accordance with the project management requirements in DOE O 413.3A, *Program and Project Management for the Acquisition of Capital Assets*, and all appropriate project management requirements have been met.

## 5. Financial Schedule

(dollars in thousands)

| | Appropriations | Obligations | Recovery Act Costs | Costs |
|---|---|---|---|---|
| Total Estimated Cost (TEC) | | | | |
| PED | | | | |
| FY 2006 | 500 | 500 | — | 88 |
| FY 2007 | 7,000 | 7,000 | — | 6,162 |
| FY 2008 | 13,377[a] | 13,377 | — | 9,108 |
| FY 2009 | 123[a] | 123 | — | 5,642 |
| Total, PED | 21,000 | 21,000 | — | 21,000 |
| Construction | | | | |
| FY 2009 | 28,500 | 28,500 | — | 2,878 |
| FY 2009 Recovery Act | 65,000 | 65,000 | 12,520 | — |
| FY 2010 | 22,000 | 22,000 | 32,200 | 29,000 |
| FY 2011 | 34,000 | 34,000 | 14,485 | 29,000 |
| FY 2012 | 66,000 | 66,000 | 4,400 | 58,622 |
| FY 2013 | 40,500 | 40,500 | 1,395 | 53,000 |
| FY 2014 | 10,500 | 10,500 | — | 26,500 |
| FY 2015 | — | — | — | 2,500 |
| Total, Construction | 266,500 | 266,500 | 65,000 | 201,500 |
| TEC | | | | |
| FY 2006 | 500 | 500 | — | 88 |
| FY 2007 | 7,000 | 7,000 | — | 6,162 |
| FY 2008 | 13,377 | 13,377 | — | 9,108 |
| FY 2009 | 28,623 | 28,623 | — | 8,520 |
| FY 2009 Recovery Act | 65,000 | 65,000 | 12,520 | — |
| FY 2010 | 22,000 | 22,000 | 32,200 | 29,000 |
| FY 2011 | 34,000 | 34,000 | 14,485 | 29,000 |
| FY 2012 | 66,000 | 66,000 | 4,400 | 58,622 |
| FY 2013 | 40,500 | 40,500 | 1,395 | 53,000 |
| FY 2014 | 10,500 | 10,500 | — | 26,500 |
| FY 2015 | — | — | — | 2,500 |
| Total, TEC | 287,500 | 287,500 | 65,000 | 222,500 |

[a] The baseline FY 2008 PED funding was reduced by $123,000 as a result of the FY 2008 rescission. This reduction is restored in FY 2009 to maintain the TEC and project scope.

| | (dollars in thousands) | | | |
|---|---|---|---|---|
| | Appropriations | Obligations | Recovery Act Costs | Costs |
| Other Project Cost (OPC) | | | | |
| OPC except D&D | | | | |
| FY 2004 | 700 | 700 | — | 77 |
| FY 2005 | 2,300 | 2,300 | — | 2,142 |
| FY 2006 | 4,000 | 4,000 | — | 3,508 |
| FY 2007 | 2,500 | 2,500 | — | 2,751 |
| FY 2008 | 1,000 | 1,000 | — | 1,802 |
| FY 2009 | — | — | — | 220 |
| FY 2013 | 2,500 | 2,500 | — | 2,400 |
| FY 2014 | 7,500 | 7,500 | — | 7,000 |
| FY 2015 | 2,000 | 2,000 | — | 2,600 |
| Total, OPC | 22,500 | 22,500 | — | 22,500 |
| Total Project Cost | | | | |
| FY 2004 | 700 | 700 | — | 77 |
| FY 2005 | 2,300 | 2,300 | — | 2,142 |
| FY 2006 | 4,500 | 4,500 | — | 3,596 |
| FY 2007 | 9,500 | 9,500 | — | 8,913 |
| FY 2008 | 14,377 | 14,377 | — | 10,910 |
| FY 2009 | 28,623 | 28,623 | — | 8,740 |
| FY 2009 Recovery Act | 65,000 | 65,000 | 12,520 | — |
| FY 2010 | 22,000 | 22,000 | 32,200 | 29,000 |
| FY 2011 | 34,000 | 34,000 | 14,485 | 29,000 |
| FY 2012 | 66,000 | 66,000 | 4,400 | 58,622 |
| FY 2013 | 43,000 | 43,000 | 1,395 | 55,400 |
| FY 2014 | 18,000 | 18,000 | — | 33,500 |
| FY 2015 | 2,000 | 2,000 | — | 5,100 |
| Total, TPC | 310,000 | 310,000 | 65,000 | 245,000 |

## 6. Details of Project Cost Estimate

| | (dollars in thousands) | | |
|---|---|---|---|
| | Current Total Estimate | Previous Total Estimate | Original Validated Estimate |
| Total Estimated Cost (TEC) | | | |
| Design (PED) | | | |
| Design | 20,150 | 19,200 | 19,200 |
| Contingency | 850 | 1,800 | 1,800 |
| Total, PED (PED no. 06-SC-01) | 21,000 | 21,000 | 21,000 |
| | | | |
| Construction Phase | | | |
| Civil Construction | 29,290 | 27,450 | 27,450 |
| Accelerator/ Experimental Equipment | 171,810 | 174,150 | 174,150 |
| Contingency | 65,400 | 64,900 | 64,900 |
| Total, Construction | 266,500 | 266,500 | 266,500 |
| Total, TEC | 287,500 | 287,500 | 287,500 |
| Contingency, TEC | 66,250 | 66,700 | 66,700 |
| | | | |
| Other Project Cost (OPC) | | | |
| OPC except D&D | | | |
| Conceptual Design | 3,445 | 3,500 | 3,500 |
| R&D | 7,020 | 6,400 | 6,400 |
| Start-up | 7,385 | 7,450 | 7,450 |
| Contingency | 4,650 | 5,150 | 5,150 |
| Total, OPC | 22,500 | 22,500 | 22,500 |
| Contingency, OPC | 4,650 | 5,150 | 5,150 |
| Total, TPC | 310,000 | 310,000 | 310,000 |
| Total, Contingency | 70,900 | 71,850 | 71,850 |

## 7. Schedule of Project Costs

For schedule of project costs, see Section 5, “Financial Schedule.”

## 8. Related Operation and Maintenance Funding requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy (fiscal quarter or date) | 3Q FY 2015 |
| Expected Useful Life (number of years) | 15 |
| Expected Future start of D&D for new construction (fiscal quarter) | N/A |

**(Related Funding requirements)**

(dollars in thousands)

| | Annual Costs | | Life cycle costs | |
|---|---|---|---|---|
| | Current Total Estimate | Previous Total Estimate | Current Total Estimate | Previous Total Estimate |
| Total Project Costs | N/A | N/A | 310,000 | 310,000 |
| Operations | 150,000 | 150,000 | 2,250,000[a] | 2,250,000[a] |
| Maintenance | Included above | Included above | Included above | Included above |
| Total, Operations & Maintenance | 150,000 | 150,000 | 2,560,000 | 2,560,000 |

## 9. Required D&D Information

| | Square Feet |
|---|---|
| Area of new construction | 31,500 |
| Area of existing facility(ies) being replaced | N/A |
| Area of any additional D&D space to meet the "one-for-one" requirement | 31,500 |

The "one-for-one" requirement is met by offsetting 31,500 square feet of the 80,000 square feet of banked space that was granted to TJNAF in a Secretarial waiver.

## 10. Acquisition Approach

The Acquisition Strategy was approved in 2Q FY 2006 with CD-1 approval. All acquisitions will be managed by Jefferson Science Associates with appropriate Department of Energy oversight. Cost, schedule and technical performance will be monitored using an earned-value process that is described in the Jefferson Lab Project Control System Manual. The procurement practice is to use firm fixed-price purchase orders and subcontracts for supplies, equipment and services, and to make awards through competitive solicitations. Project and design management, inspection, coordination, tie-ins, testing and checkout witnessing, and acceptance will be performed by TJNAF and A-E subcontractors as appropriate.

[a] The total operations and maintenance (O&M) is estimated at an average annual cost of ~$150,000,000 (including escalation) over 15 years. Almost 90% of the O&M cost would still have been required had the existing accelerator not been upgraded and instead continued operations at 6 GeV.

## Fusion Energy Sciences

## Funding Profile by Subprogram

(dollars in thousands)

| | FY 2008 Current Appropriation | FY 2009 Original Appropriation | FY 2009 Additional Appropriation[a] | FY 2010 Request |
|---|---|---|---|---|
| Fusion Energy Sciences | | | | |
| Science | 155,032 | 172,387 | +56,511 | 176,067 |
| Facility Operations | 116,968 | 207,253 | +34,512 | 221,742 |
| Enabling R&D | 22,933 | 22,910 | — | 23,191 |
| Total, Fusion Energy Sciences | 294,933[bc] | 402,550 | +91,023 | 421,000 |

**Public Law Authorizations:**
Public Law 95–91, "Department of Energy Organization Act", 1977
Public Law 109–58, "Energy Policy Act of 2005"
Public Law 110–69, "America COMPETES Act of 2007"

## Program Overview

### Mission

The mission of the Fusion Energy Sciences (FES) program is to expand the fundamental understanding of matter at very high temperatures and densities and to build the scientific foundations needed to develop a fusion energy source. This is accomplished by studying plasmas under a wide range of temperature and density conditions, developing advanced diagnostics to make detailed measurements of plasma properties, and creating theoretical/computational models to resolve the essential physics.

### Background

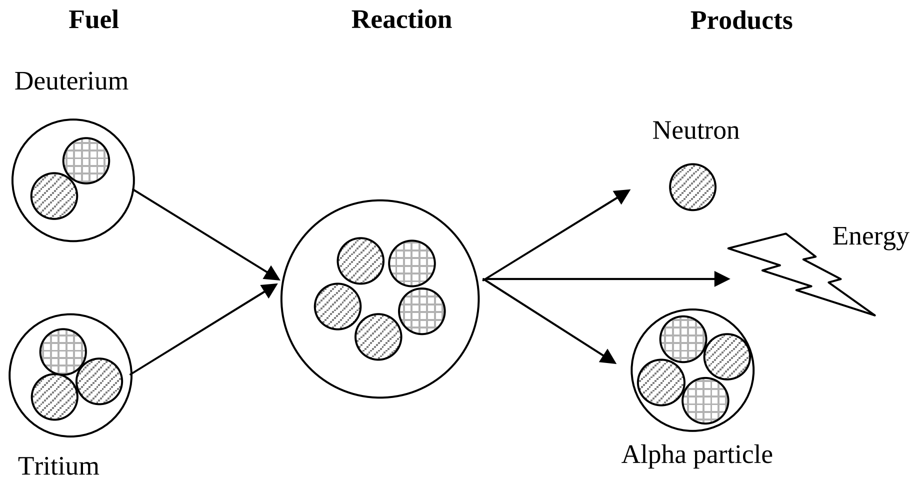
Since 1929, when the American chemist Irving Langmuir first used the word *plasma* (from the Greek for "moldable substance") to describe a collection of charged particles—electrons and ions—in electric discharges, research in plasma physics has grown considerably. Early research in plasma physics was limited to gas discharges, ionospheric physics, and astrophysics; however, today plasma physics is a broad and rich discipline. Progress in our understanding of plasma behavior has had significant impacts on applications of commercial interest—such as semiconductor processing, displays and lighting, and other low temperature plasma applications—where science-based methods have replaced empirical approaches.

The field of plasma physics experienced significant growth in the early 1950s when the U.S. and other nations decided to pursue fusion as a possible energy source. Understanding the behavior of fusion plasmas quickly emerged as a critical scientific issue, and fusion became the main driver for plasma physics research from the late 1950s to the present day. Fusion energy offers the promise of a fundamentally new and attractive energy source based on the nuclear fusion process. FES is developing

[a] The additional Appropriation column reflects the planned allocation of funding from the American Recovery and Reinvestment Act of 2009, P.L. 111–5. See the Department of Energy Recovery website at http://www.energy.gov/recovery for up-to-date information regarding Recovery Act funding.
[b] Includes $15,500,000 provided by the Supplemental Appropriations Act, 2008, P.L. 110–252.
[c] Total is reduced by $7,115,000: $6,353,000 of which was transferred to the SBIR program and $762,000 of which was transferred to the STTR program.

the scientific underpinnings of potential fusion energy systems. In order to carry out this charge, FES has emerged as the nation's primary steward of the field of plasma physics and, in cooperation with the National Nuclear Security Administration (NNSA), the field of high energy density laboratory plasmas (HEDLP).

Since the earliest work on fusion energy, most fusion reactor concepts have shared a common "recipe" the fusion fuel (usually a mixture of the hydrogen isotopes deuterium and tritium) is heated to extremely high temperatures (on the order of 100 million degrees) creating a plasma of ionized deuterium and tritium. Under these conditions, the deuterium and tritium nuclei fuse, releasing substantial amounts of energy.




**The Fusion Process**

Creating a burning plasma is the crucial next step in the magnetic fusion energy science (MFES) program. A burning plasma is fundamentally different from the plasmas that have been created in research facilities to date, which have all been sustained entirely by external energy sources. In a burning plasma, the plasma temperature is sustained primarily by the self-heating by the alpha particles produced by the fusion reactions.

To sustain the fusion reaction process and keep the fusion fuel at thermonuclear temperatures, the plasma must be contained and prevented from coming into contact with the comparatively cool walls of the confining vessel. In the decades that followed the first attempts at controlled thermonuclear fusion, two main approaches for confining fusion plasmas emerged: magnetic confinement and inertial confinement. FES supports research programs in MFES and in plasma science, including activities to investigate the fundamental science of HEDLP needed to make inertial fusion energy attractive.

The MFES program is now moving into the burning plasma regime through its participation in ITER, an international fusion research facility under construction in Cadarache, France, which is designed to achieve and investigate the characteristics of a burning plasma. Under the ITER Joint Implementation Agreement (JIA), the United States is a full Member of the International ITER project—an unprecedented international scientific endeavor to explore the physics of burning plasmas. Our 9.09% share of ITER gives the U.S. access to all scientific data, gives the U.S. the right to propose and carry out experiments, and creates new opportunities for U.S. industry to manufacture high-technology components to fulfill a large part (roughly 80%) of our contribution. In addition to ITER, the United States collaborates with these partners on current fusion research facilities and programs through International Energy Agency (IEA) and bilateral agreements.

With the initiation of the ITER project and the recent completion of the NNSA's National Ignition Facility (NIF) at the Lawrence Livermore National Laboratory (LLNL), plasma science research is at the threshold of new discoveries that will transform the field. Magnetic fusion science has progressed to the point where the community has the knowledge not only to design a burning plasma device (ITER), but also to identify the broader scientific and technical questions that remain to be answered on the path to fusion energy. It is thus an opportune time for the FES program to tackle a wide range of scientific and technical challenges to the development of practical fusion energy.

The FES mission is advanced by three strategic goals reflecting the structure of our program and a synthesis of input from the National Academies, the Fusion Energy Sciences Advisory Committee (FESAC), and the U.S. fusion community. These distinct but strongly linked and synergistic goals are unified by fundamental plasma science, the scientific foundation for a fusion energy source.

- Advance the fundamental science of magnetically confined plasmas to develop the predictive capability needed for a sustainable fusion energy source;
- Pursue scientific opportunities and grand challenges in high energy density plasma science to better understand our universe, to enhance national security and economic competitiveness, and to explore the feasibility of the inertial confinement approach as a fusion energy source; and
- Increase the fundamental understanding of basic plasma science, including low temperature plasma science and engineering, to enhance economic competiveness and to create opportunities for a broader range of science-based applications.

The research activities supported by FES have led to a wide range of advances in fusion related sciences. Some representative advances include the achievement of an increase in fusion power output in laboratory experiments by 12 orders of magnitude over the past 3 decades, the development of advanced computation and simulation capability in the areas of energy transport and plasma stability needed to design a tokamak capable of achieving a burning plasma with significant fusion energy output, and the initiation of the 35-year U.S. participation in the ITER project.

**Subprograms**

To accomplish its mission and address the strategic goals described above, the FES program is organized into three subprograms—Science, Facility Operations, and Enabling R&D.

- The *Science* subprogram is developing a predictive understanding of fusion plasmas in a range of plasma confinement configurations. The emphasis is presently weighted towards understanding the plasma state and its properties for stable fusion systems, but increasing emphasis is expected in the areas of plasma-material interaction and the simultaneous effects of high heat and neutron fluxes that will be encountered in a burning plasma environment. This subprogram contains research activities in magnetic fusion energy science and in plasma science, including activities to investigate the fundamental science of HEDLP needed to make inertial fusion energy attractive.
- The *Facility Operations* subprogram includes efforts to build, operate, maintain, and upgrade the large facilities needed to carry out research on fusion energy science. The U.S. is a full partner in the international program to design and build ITER, the first fusion facility large enough to sustain a burning plasma. The Facility Operations subprogram includes the funding for the U.S. share of the ITER project. The three major experimental facilities in the FES program—DIII-D tokamak at General atomics in San Diego, California; the Alcator C-Mod tokamak at the Massachusetts Institute of Technology (MIT) in Cambridge, Massachusetts; and the National Spherical Torus Experiment (NSTX) at Princeton Plasma Physics Laboratory (PPPL) in Princeton, New Jersey - provide the essential tools for the U.S. research community to explore and solve fundamental issues of fusion

plasma physics. All three are operated as national facilities and involve users from many laboratories and universities. The funding for facility operations includes expenses for running the facility, providing the required plasma diagnostics, and for facility maintenance, refurbishment, and minor upgrades. The balance between maintenance, upgrades, and experimental operations is judiciously adjusted to ensure safe operation of each facility, provide modern experimental tools such as heating, fueling, and exhaust systems, and provide maximum operating time for the scientists.

- The *Enabling R&D* subprogram supports research to improve the components and systems that are used to build fusion facilities, thereby enabling both existing and future U.S. fusion facilities to achieve improved performance and bring us closer to the goal of achieving practical fusion energy.

**Benefits to Society**

The development of plasma science during the past 50 years has been motivated by a diverse set of applications such as astrophysics, space science, plasma processing, national defense, and fusion energy. Advances in plasma science have led to significant present day applications, such as plasma processing of semiconductors and computer chips, material hardening for industrial and biological uses, waste management techniques, lighting and plasma displays, space propulsion, and has led to the development of non-contact infection-free surgical scalpels. Particle accelerators and free electron lasers also rely on plasma science concepts.

Plasma science is essential to the development of fusion energy. Fusion has the potential to provide an energy source that is virtually inexhaustible and environmentally benign, producing no combustion products or greenhouse gases. While fusion is a nuclear process, the products of the fusion reaction (helium and a neutron) are not intrinsically radioactive. Short-lived radioactivity may result from interactions of the fusion products with the reactor walls, but with proper design a fusion power plant would be passively safe, and would produce no long-lived radioactive waste. Design studies show that electricity from fusion should eventually cost about the same as electricity from present day sources.

The extreme states of matter studied in HEDLP and encountered in inertial confinement fusion studies may offer an alternate path to a fusion energy source. This research is related to the NNSA stockpile stewardship program and, hence, indirectly supports the national security program of DOE. Related areas of science addressed in these research programs include turbulence and complex systems, multiphase interactions and plasma-material interactions, self-organization of complex systems, astrophysics, geodynamics, and fluids.

**Program Planning and Management**

FES uses a variety of external entities to gather input for making informed decisions on programmatic priorities and allocation of resources. As part of this effort, FES has developed a system of planning and priority setting that draws on advice from groups of outside experts. FES has also instituted a number of peer review and oversight measures designed to assess productivity and maintain effective communication and coordination among participants in FES activities.

In 2004, a National Academies Press report entitled *Burning Plasma—Bringing a Star to Ear*th indicated that ITER "should be the top priority in a balanced US fusion science program." To coordinate the near term support for ITER, and to prepare for the eventual operation and participation by U.S. scientists in ITER, the FES set up the U.S. Burning Plasma Organization (USBPO). The USBPO Director is also the chief scientist for the U.S. ITER Project Office (USIPO), thus providing close coupling between the ITER Project activities and these scientific activities. The U.S. is also a very active member of the International Tokamak Physics Activity (ITPA) which facilitates international coordination of tokamak research in support of ITER.

The National Research Council (NRC) Plasma Science Committee, which serves as a continuing connection to the general plasma physics community, completed a review in 2007 of plasma science. The report, entitled *Plasma Science-Advancing Knowledge in the National Interest* concluded that expanding the scope of plasma research creates an abundance of new scientific opportunities and challenges. This recommendation supports and informs the FES effort to create a balanced U.S. fusion science program with the FES program as the stewards of general plasma science.

FES is currently engaged in a community-wide effort, culminating in a MFES Research Needs Workshop (ReNeW) scheduled for June 2009, to describe the scientific research required in the ITER era to close knowledge gaps. The information from this activity, along with input from other sources including research needs workshops in Plasma Sciences and HEDLP, will be used by DOE in developing a long-range strategic plan for the FES program.

FES also takes into consideration reports and recommendations from the Fusion Energy Sciences Advisory Committee (FESAC)—a standing committee organized in accordance with the Federal Advisory Committee Act (FACA). Two recent FESAC reports, "Priorities, Gaps and Opportunities: Towards a Long-Range Strategic Plan for Magnetic Fusion Energy" and "Report of the FESAC Toroidal Alternates Panel" have provided a foundation for long-range strategic planning for the MFES part of the program. Those reports, together with earlier reports on burning plasma and ITER research issues, document the full spectrum of science and technology issues and knowledge gaps arising on the ITER path to fusion energy. These reports were used as the technical basis for the ReNeW workshop, which will be input for a new strategic plan for the U.S. fusion science program due to completed in FY2010.

FESAC also completed in 2009 a study of the scientific issues and opportunities in HEDLP entitled, "Advancing the Science of High Energy Density Laboratory Plasmas." This report documents the issues and opportunities in both fundamental and mission-driven HEDLP that can be pursued over the next decade through the joint FES-NNSA program in HEDLP. This report will be used as the technical basis for the HEDLP ReNeW workshop that will be held in August 2009. The output from this workshop will support the HEDLP portion of the new strategic plan.

FES has required the three major experimental facilities supported by the program to have Program Advisory Committees (PACs). The PACs serve an extremely important role in providing guidance to the facility directors in the form of program review and advice regarding allocation of facility run-time. Composed primarily of researchers from outside the host facility, these PACs also include non-U.S. members.

FESAC also convenes a Committee of Visitors (COV) panel to review FES program management practices every three years. A new COV charge was given to FESAC in November 2008. It asks FESAC to review the entire FES program and report its findings to DOE by August 2009.

## Basic and Applied R&D Coordination

As recommended in 2007 by the National Science and Technology Council in the *Report of the Interagency Task Force on High Energy Density Physics*, FES and NNSA have established a joint program in HEDLP to provide stewardship of high energy density laboratory plasma physics. The benefits of this joint program are that it will avoid duplication of effort, provide better leverage for the FES high energy density physics projects of the NNSA high energy density (HED) facilities, and stimulate synergies between the two programs and interactions among the researchers. High energy density plasmas are plasmas with pressures exceeding one million atmospheres (greater than 1 megabar). The science of high energy density plasmas is important to science-based nuclear stockpile stewardship as well as to the research on inertial fusion energy. The FES high energy density physics program includes energy-related science and other fundamental research (e.g., laboratory astrophysics).

At the present time this research includes the science of fast ignition, laser-plasma interaction, magnetized high energy density plasmas, high-density high Mach-number plasma jets, and heavy-ion-beam driven warm dense matter. This research overlaps with other areas of HEDLP that are being funded by the NNSA and are important to nuclear stockpile stewardship including compressible and radiative hydrodynamics, laser-plasma interactions, material properties under extreme conditions, and laboratory astrophysics. The research activities of FES and NNSA in HEDLP are being coordinated under a joint program, with coordinated solicitations, peer reviews, scientific workshops, and Federal advisory functions.

**Budget Overview**

The FES program is the primary supporter of research in the field of plasma physics. The FY 2010 budget request of $421,000,000 is designed to optimize, within these resources, the scientific productivity of the program. The FES program funds activities involving over 1,100 researchers and students at approximately 67 universities, 10 industrial firms, 11 national laboratories, and 2 Federal laboratories, all of which are located in 31 states. Some of the key activities of the FES program and their status in the FY 2010 budget year are:

- The United States will fully fund our share of the Construction Phase of the ITER Project (U.S. Contributions to ITER Project) including research and development of key components, long-lead procurements, and contributions of personnel and funds to the ITER Organization (IO). In addition, the U.S., working in conjunction with the other partners, will continue to advocate the establishment of formal, coherent, and disciplined project management practices by the IO as a means to control schedule and cost.
- Research at the major experimental facilities in the FES program—DIII-D, Alcator C-Mod, and NSTX—will continue to focus on providing solutions to key high–priority ITER issues and build a firm physics basis for ITER design and operation. More specifically, these facilities will conduct experiments to improve active control of various plasma parameters, measure the effects and mitigation of disruptions in the plasma, develop a better understanding of the physics of the plasma edge in the presence of large heat flows, control the current density profile for better stability, and develop a scientific basis of advanced operating scenarios for ITER.
- The planning study of the Fusion Simulation Program (FSP) continues following a modest start in FY 2009. The FSP is a computational initiative led by FES with collaborative support from the Office of Advanced Scientific Computing Research (ASCR). It is aimed at the development of a world-leading, experimentally validated, predictive simulation capability for fusion plasmas in the regimes and geometries relevant for practical fusion energy.
- As part of stewardship of plasma science, FES will continue to provide support for the operation of one to two plasma science centers (PSCs). The PSCs are intended to establish academic centers of excellence that will focus on fundamental issues of widely recognized importance to plasma science. The education and training of plasma scientists is a major goal of this program.
- FES is also well underway in implementing a joint program of research with NNSA in HEDLP that was started in FY 2008. This program will advance the exploration of a number of fields of research indentified as priorities by both the National Academies and FESAC. In particular, it will continue its support of basic research on the science of fast ignition, laser-plasma interaction, magnetized high energy density plasmas, plasma jets, and warm dense matter.

## Significant Program Shifts

FES terminated the National Compact Stellarator Experiment (NCSX) project at PPPL in FY 2008. Funding that was planned for the continuation of NCSX in FY 2009 and FY 2010 is being redirected to increase operating time of the three large facilities, enhance the research programs on smaller stellarators, and initiate an upgrade of NSTX at PPPL. NSTX upgrades will help us better understand the physics required to successfully operate and fully exploit the investment in ITER and may provide important insights into the design of a future domestic facility.

## Strategic and GPRA Unit Program Goals

The FES program has one Government Performance and Results Act (GPRA) Unit Program goal which contributes to Strategic Goal 3.1 and 3.2 in the "goal cascade":

- GPRA Unit Program Goal 3.1/2.49.00: Bring the Power of the Stars to Earth—Answer the key scientific questions and overcome enormous technical challenges to harness the power that fuels our Sun.

## Contribution to GPRA Unit Program Goal 3.1/2.49.00, Bring the Power of the Stars to Earth

The FES program contributes to this goal by managing a program of fundamental research into the nature of fusion plasmas and the means for confining plasma to yield energy. This program includes exploring basic issues in plasma science; developing the scientific basis and computational tools to predict the behavior of magnetically confined plasmas; using the advances in tokamak research to enable the initiation of the burning plasma physics phase of the FES program; exploring innovative confinement options that offer the potential to increase the scientific understanding and to improve the confinement of plasmas in various configurations; investigating non-neutral plasmas and high energy density physics; and developing the cutting edge technologies that enable fusion facilities to achieve their scientific goals.

These activities require operation of a set of unique and diversified experimental facilities, including smaller-scale devices at universities involving individual principal investigators, larger national facilities that require extensive collaboration among domestic institutions, and an even larger, more costly experiment that requires international collaborative efforts to share the costs and gather the scientific and engineering talents needed to undertake such an experiment. These facilities provide scientists with the means to test and extend theoretical understanding and computer models—leading ultimately to an improved predictive capability for fusion science.

The specific long term (10 year) goals for scientific advancement to which the FES program is committed and against which progress can be measured are:

- **Predictive Capability for Burning Plasmas**: Progress toward developing a predictive capability for key aspects of burning plasmas using advances in theory and simulation benchmarked against a comprehensive experimental database of stability, transport, wave-particle interaction, and edge effects.
- **Configuration Optimization**: Progress toward demonstrating enhanced fundamental understanding of magnetic confinement and improved basis for future burning plasma experiments through research on magnetic confinement configuration optimization.
- **High Energy Density Plasma Physics**: Progress toward developing the fundamental understanding and predictability of high energy density plasma physics.

## Annual Performance Results and Targets

| FY 2005 Results | FY 2006 Results | FY 2007 Results | FY 2008 Results | FY 2009 Targets | FY 2010 Targets |
|---|---|---|---|---|---|
| GPRA Unit Program Goal 3.1/2.49.00 (Bring the Power of the Stars to Earth) | | | | | |
| Science | | | | | |
| Conduct experiments on the major fusion facilities (DIII-D, Alcator C-Mod and NSTX) leading toward the predictive capability for burning plasmas and configuration optimization. In FY 2005, FES measured plasma behavior in Alcator C-Mod with high-Z antenna guards and input power greater than 3.5 MW. [Met Goal] | Conduct experiments on the major fusion facilities (DIII-D, Alcator C-Mod, and NSTX) leading toward the predictive capability for burning plasmas and configuration optimization. In FY 2006, FES injected 2 MW of neutral power in the counter direction on DIII-D and began physics experiments. [Met Goal] | Conduct experiments on major fusion facilities leading toward the predictive capability for burning plasmas and configuration optimization. In FY 2007, FES measured and identified magnetic modes on NSTX that were driven by energetic ions traveling faster than the speed of magnetic perturbations (Alfvén speed); such modes are expected in burning plasmas such as ITER. [Met Goal] | Conduct experiments on major fusion facilities leading toward the predictive capability for burning plasmas and configuration optimization. In FY 2008, FES evaluated the generation of plasma rotation and momentum transport, and assessed the impact of plasma rotation on stability and confinement. Alcator C-Mod investigated rotation without external momentum input, NSTX examined very high rotation speeds, and DIII-D varied rotation speeds with neutral beams. The results achieved at the major facilities provided important new data for estimating the magnitude of and assessing the impact of rotation on ITER plasmas. [Met Goal] | Conduct experiments on major fusion facilities to develop understanding of particle control and hydrogenic fuel retention in tokamaks. In FY 2009, FES will identify the fundamental processes governing particle balance by systematically investigating a combination of divertor geometries, particle exhaust capabilities, and wall materials. Alcator C-Mod operates with high-Z metal walls, NSTX is pursuing the use of lithium surfaces in the divertor, and DIII-D continues operating with all graphite walls. Edge diagnostics measuring the heat and particle flux to walls and divertor surfaces, coupled with plasma profile data and material surface analysis, will provide input for validating simulation codes. The results achieved will be used to improve extrapolations to planned ITER operation. | Conduct experiments on major fusion facilities to improve understanding of the heat transport in the tokamak scrape-off layer (SOL) plasma, strengthening the basis for projecting divertor conditions in ITER. The divertor heat flux profiles and plasma characteristics in the tokamak SOL will be measured in multiple devices to investigate the underlying thermal transport processes. The unique characteristics of C-Mod, DIII-D, and NSTX will enable collection of data over a broad range of SOL and divertor parameters (e.g., collisionality, beta, parallel heat flux, and divertor geometry). Coordinated experiments using common analysis methods will generate data that will be compared with theory and simulation. |

| FY 2005 Results | FY 2006 Results | FY 2007 Results | FY 2008 Results | FY 2009 Targets | FY 2010 Targets |
|---|---|---|---|---|---|
| Increase resolution in simulations of plasma phenomena—optimizing confinement and predicting the behavior of burning plasmas require improved simulations of edge and core plasma phenomena, as the characteristics of the edge can strongly affect core confinement. In FY 2005, FES simulated nonlinear plasma edge phenomena using extended MHD codes with a resolution of 20 toroidal modes. [Met Goal] | Increase resolution in simulations of plasma phenomena—optimizing confinement and predicting the behavior of burning plasmas require improved simulations of edge and core plasma phenomena, as the characteristics of the edge can strongly affect core confinement. In FY 2006, FES simulated nonlinear plasma edge phenomena using extended MHD codes with a resolution of 40 toroidal modes. [Met Goal] | Increase resolution in simulations of plasma phenomena—optimizing confinement and predicting the behavior of burning plasmas require improved simulations of edge and core plasma phenomena, as the characteristics of the edge can strongly affect core confinement. In FY 2007, FES improved the simulation resolution of linear stability properties of Toroidal Alfvén Eigenmodes driven by energetic particles and neutral beams in ITER by increasing the number of toroidal modes used to 15. [Met Goal] | Increase resolution in simulations of plasma phenomena—optimizing confinement and predicting the behavior of burning plasmas require improved simulations of edge and core plasma phenomena, as the characteristics of the edge can strongly affect core confinement. In FY 2008, the simulation resolution of ITER-relevant modeling of lower hybrid current drive experiments on Alcator C-Mod was improved by increasing the number of poloidal modes used to 2,000 and the number of radial elements used to 1,000 using the leadership class computers at ORNL. [Met Goal] | Continue to increase resolution in simulations of plasma phenomena—optimizing confinement and predicting the behavior of burning plasmas require improved simulations of edge and core plasma phenomena, as the characteristics of the edge can strongly affect core confinement. In FY 2009, gyrokinetic edge electrostatic turbulence simulations will be carried out across the divertor separatrix with enhanced resolution down to the ion gyroradius scale. | Optimizing confinement and predicting the behavior of burning plasmas require improved simulations of toroidal momentum transport, since it influences plasma rotation which plays a critical role in reducing the loss of heat from the plasma and in stabilizing macroscopic instabilities. In FY 2010, gyrokinetic simulations of turbulent transport of toroidal momentum with Boltzmann and with kinetic electrons will be carried out. These simulations will explore the Ion Temperature Gradient (ITG) and the Collisionless Trapped Electron Mode (CTEM) regimes. |
| Facility Operations | | | | | |
| Average achieved operational time of major national fusion facilities as a percentage of total planned operational time is greater than 90%.[Met Goal] | Average achieved operational time of major national fusion facilities as a percentage of total planned operational time is greater than 90%. [Met Goal] | Average achieved operational time of major national fusion facilities as a percentage of total planned operational time is greater than 90%. [Met Goal] | Average achieved operational time of major national fusion facilities as a percentage of total planned operational time is greater than 90%. [Met Goal] | Average achieved operational time of major national fusion facilities as a percentage of total planned operational time is greater than 90%. | Average achieved operational time of major national fusion facilities as a percentage of total planned operational time is greater than 90%. |
| Cost-weighted mean percent variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects kept to less than 10%. [Met Goal] | Cost-weighted mean percent variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects kept to less than 10%. [Met Goal] | Cost-weighted mean percent variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects kept to less than 10%. The NCSX team has concluded that the project cannot be completed within the cost and schedule baseline. [Goal Not Met] | Cost-weighted mean percent variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects kept to less than 10%. The NCSX project was cancelled. [Goal Not Met] | Cost-weighted mean percent variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects kept to less than 10%. | Cost-weighted mean percent variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects kept to less than 10%. |

## Science

### Funding Schedule by Activity

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Science | | | |
| Tokamak Experimental Research | 51,622 | 50,522 | 51,441 |
| Alternative Concept Experimental Research | 57,003 | 65,566 | 65,595 |
| Theory | 24,505 | 24,176 | 24,283 |
| Advanced Fusion Simulations | 7,081 | 9,188 | 11,212 |
| General Plasma Science | 14,821 | 14,869 | 14,869 |
| SBIR/STTR | — | 8,066 | 8,667 |
| Total, Science | 155,032 | 172,387 | 176,067 |

### Description

Plasmas are electrically charged gases that are influenced by the long range interactions between the ions and electrons and by magnetic fields, either externally applied or generated by currents within the plasma. Thus, the Science subprogram focuses on two key questions: What are the physical processes that govern the behavior of a plasma, especially a high temperature plasma? How do you create, confine, heat, and control a burning plasma to make fusion power a reality? These two questions are inherently linked, since a profound understanding of plasma science will be needed to learn how to bring the power of the stars to earth. This linkage is captured in a major goal of the Science subprogram which is to develop a predictive understanding of high temperature fusion burning plasmas in a range of confinement configurations.

The Science subprogram is supporting the preparation for the eventual exploration of burning plasmas by addressing the question of how high temperature plasmas behave in a tokamak based magnetic configuration. The Science subprogram is focused on advancing understanding of plasmas and the fusion environment through an integrated program of experiments, theory, and simulation as outlined in the FESAC report, *Scientific Challenges, Opportunities and Priorities for the Fusion Energy Sciences Program*. This research program aims to yield new methods for sustaining and controlling high temperature, high-density plasmas, which will have a major impact on ITER operation. Research on ITER is expected to provide sufficient information on the complex science of burning plasmas to make a definitive assessment of the scientific feasibility of fusion power.

In parallel with supporting the eventual burning plasma program of ITER, the Science subprogram is pursuing the development of advanced computational simulation tools, capable of taking advantage of the emerging petascale computing resources, needed to address and predict in an integrated manner the questions of how a burning plasma will behave—the Fusion Simulation Program (FSP). This effort will yield the computational tools needed to fully utilize ITER as a science tool. It should also keep the U.S. science community in the lead in using high performance computers to advance understanding of the plasma state.

Addressing the scientific questions associated with the behavior of high temperature plasmas requires a close collaboration between theorists, computational scientists, and experimentalists. In an effort to make this a close and effective collaboration, the Science subprogram is initiating an integrated national science campaign. This science campaign will create a team of scientists from the three major FES facilities, working with theorists and computational scientists to understand the properties of the tokamak edge plasma. Understanding the plasma edge will be a major advance for the fusion program since the edge appears to determine many of the properties of a tokamak plasma. In particular the performance of ITER will likely be determined by the properties of the edge plasma.

The majority of the plasma science questions being addressed within the Science subprogram are closely linked with addressing the question of how to bring the power of the stars to the laboratory. However, there are a number of plasma science questions that do not have this linkage, and these questions are addressed in the General Plasma Science and the Alternative Concepts Experimental Research parts of the Science subprogram. Examples of the plasmas that are being explored are low temperature plasmas used in industrial processing, HEDLP for national security, plasmas for space propulsion, and astrophysics plasmas. An additional objective of the Science subprogram is to broaden the intellectual and institutional base in fundamental plasma science and HEDLP. Two activities, a National Science Foundation (NSF)/DOE partnership in plasma physics and engineering, and the Plasma Physics Junior Faculty Development Program for early career university faculty members, will continue to contribute to this objective. The ongoing Plasma Science Centers (PSCs), funded under General Plasma Science, will also foster fundamental understanding and connections to these related sciences.

**Selected FY 2008 Accomplishments**

- *World's first gyrokinetic turbulence simulation in realistic edge plasma:* Researchers at the Scientific Discovery through Advanced Computing (SciDAC) Center for Plasma Edge Simulation carried out simulations of plasma turbulence in the edge of the DIII-D tokamak. These simulations showed the existence of ion temperature gradient (ITG) turbulence, in the entire edge region of the plasma—even where the local conditions for the existence of the ITG turbulence were not satisfied. This unexpected result established for the first time the non-local nature of this turbulence mode. The ion thermal transport calculated in the ITG turbulence simulation agreed with the experimentally observed value.
- *Coordinated research effort to examine rotation physics:* A coordinated research campaign was conducted through the three major FES facilities to explore multiple aspects of plasma rotation on turbulence, transport, and stability in tokamaks. Alcator C-Mod investigated active rotation drive using radio waves. DIII-D used magnetic perturbations to increase the rotation of a tokamak plasma for the first time, and NSTX utilized various combinations of magnetic perturbations and modulated neutral beam injection to study momentum sources and sinks in the plasma. Additional experiments at the three facilities provided important data on intrinsic plasma rotation (the rotation observed in plasmas with no external source of momentum input), validating a theory toroidal plasma viscosity, and understanding the role of rotational shear on energy transport. Since rotation generally has favorable effects on turbulence, transport, and stability, these results have important implications for ITER.
- *Mode conversion flow drive:* Experiments on Alcator C-Mod demonstrated that significant toroidal and poloidal plasma flow can be driven by radio frequency (RF) waves. This was an unexpected result, but one of significant importance, since plasma flows are important for achieving good plasma confinement and stability. This result has important implications for ITER, since it may be possible to affect energy transport in a burning plasma using RF flow drive
- *Highest magnetic field achieved in dense plasma in the laboratory at the OMEGA Laser Facility:* Magnetic flux in dense plasmas has been compressed to generate a field of more than 30 million gauss using lasers at the University of Rochester's OMEGA facility. Such high fields are expected to have a significant effect on the properties of a plasma, but the behavior of dense plasmas in high

magnetic fields is a relatively unexplored regime of high energy density plasma physics. This accomplishment paves the way for studying the behavior of dense plasmas in high magnetic fields and developing potentially attractive schemes for inertial fusion energy.

## Detailed Justification

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| **Tokamak Experimental Research** | **51,622** | **50,522** | **51,441** |

The tokamak magnetic confinement concept has to date been the most effective approach for confining high-temperature plasmas in a laboratory environment. Many of the important issues in fusion science are being studied in tokamaks, including the two major U.S. tokamak facilities: DIII-D and Alcator C-Mod. In association with the International Tokamak Physics Activity (ITPA), the U.S. tokamaks continue to give high priority to joint experiments with tokamak facilities in Europe and Japan to resolve ITER-relevant physics issues. Through the ITER project, the tokamak will, for the first time, offer fusion scientists the opportunity to create, control, and probe a burning plasma.

Today, tokamak experimental research is marked by plasma measurements of unprecedented detail and accuracy, excellent plasma control, and strong connections to theory and simulation efforts. Both DIII-D and Alcator C-Mod use flexible plasma shaping and dynamic control capabilities to attain good confinement and stability. They control the distribution of current in the plasma with electromagnetic wave heating and current drive. The interface between the plasma edge and the material walls of the confinement vessel is managed by means of a magnetic “divertor” and magnetic coils for fine control. Through tokamak research, the science of plasma confinement, plasma control, plasma responses to heating and fueling sources, and plasma-wall interactions has matured sufficiently to establish the physics basis for ITER and continues to advance rapidly. In FY 2010, U.S. tokamak researchers will continue to expand the frontiers of fusion science, both to address outstanding ITER issues and to develop the basis for practical fusion power plants.

Both DIII-D and Alcator C-Mod are operated as national collaborative science facilities with research programs established through public research forums, program advisory committee recommendations, and peer review. As the new superconducting tokamak programs in China (Experimental Advanced Superconducting Tokamak, EAST) and Korea (Korean Superconducting Tokamak Advanced Research, KSTAR) advance their research operations, increases in international collaborations are planned to address steady state physics and technology issues that are not currently being addressed on U.S. facilities.

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| ▪ **DIII-D Research** | **27,451** | **26,488** | **26,604** |

The DIII-D tokamak is the largest magnetic fusion facility in the U.S. DIII-D provides for considerable experimental flexibility and has extensive diagnostic instrumentation to measure the properties of high temperature plasmas. It also has unique capabilities to shape the plasma and provide feedback control of error fields that, in turn, affect particle transport and plasma stability. DIII-D has been a major contributor to the world fusion program over the past decade in the areas of plasma turbulence, energy and particle transport, electron-cyclotron plasma heating and current drive, plasma stability, and boundary layer physics using a “magnetic divertor” to control the magnetic field configuration at the edge of the plasma. The divertor is produced by magnet coils that bend the magnetic field at the edge of the tokamak out into a region where plasma particles following the field are neutralized and pumped away.

| | (dollars in thousands) | | |
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| | FY 2008 | FY 2009 | FY 2010 |

The primary goal of the DIII-D program is to establish the scientific basis for the optimization of the tokamak approach to fusion energy. This is being accomplished by advancing basic scientific understanding across a broad front of fusion plasma topical areas including transport, stability, plasma-wave physics, and interactions with physical boundaries. These topics are integral parts of six physics groups in the DIII-D Experimental Science Division structure, which are: Steady State Integration, Integrated Modeling, ITER Physics, Plasma Control and Operations, Fusion Science, and Plasma Boundary Interfaces. In addition, three cross-cutting task groups focus on rapid shutdown schemes for ITER, the physics of non-axisymmetric field effects for ITER, and transport model validation. Over the past few years, the investigation of ITER-relevant discharge scenarios, including the development of advanced enhanced performance scenarios, has gained emphasis in the DIII-D experimental program.

The FY 2010 experimental program on DIII-D will commence in mid-October 2009, after a short maintenance period following FY 2009 operations. The objective will be to complete a 14 week research campaign by mid-June and then begin a major hardware modification effort (primarily involving re-orientation of one of the neutral beam lines for off-axis current drive capability) which is planned to take 11 months to finish. The FY 2010 experimental program will continue to focus on experiments to provide solutions to key ITER issues and build a firm physics basis for ITER program planning. The DIII-D program will also be able to accommodate a number of ITPA joint experiments in collaboration with the international community.

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| ▪ **Alcator C-Mod Research** | **9,502** | **9,027** | **9,030** |

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. It is the only tokamak in the world operating at and above the ITER design magnetic field and plasma densities, and it produces the highest pressure tokamak plasma in the world, approaching pressures expected in ITER. It is also unique in the use of all-metal walls to accommodate high power densities. By virtue of these characteristics, Alcator C-Mod is particularly well suited to operate in plasma regimes that are relevant to ITER. The facility has made significant contributions to the world’s fusion program in the areas of plasma heating, stability, confinement, non-inductive current drive and rotational flows in high field tokamaks, all of which are important integrating issues for burning plasmas.

In FY 2010, Alcator C-Mod will continue a strong research program primarily in support of ITER. Experiments will continue to elucidate the physics of electron runaway dynamics during tokamak discharge disruptions and characterization of small edge-localized modes. Both of these topics are of vital importance to ITER performance: runaway electrons generated during disruptions can damage tokamak walls and controlling the size of the edge-localized modes impacts both the transport properties of the discharge and protection of the tokamak divertor and plasma facing components.

Other ITER-relevant topics that the Alcator C-Mod team will continue to focus on in FY 2010 include plasma surface interaction with all-metal walls (especially in the divertor area), measuring the effects of and mitigating disruptions in the plasma, understanding the physics of the plasma edge in the presence of large heat flows, controlling the current density profile for better stability, and helping to build international cross-machine databases using dimensionless parameter techniques. The main effort will shift to developing accurate models of the fuel retention process in first-wall tiles, an activity important both to ITER and to DEMO-like future machines. C-Mod

| | (dollars in thousands) | | |
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| | FY 2008 | FY 2009 | FY 2010 |

will continue participation in many joint experiments organized by the ITPA involving all seven ITER members.

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| ▪ **International Research** | **5,014** | **4,897** | **4,900** |

In addition to their work on domestic experiments, scientists from the FES program participate in leading edge scientific experiments on fusion facilities abroad in Europe, Japan, China, South Korea, the Russian Federation, and India—the ITER members—and conduct comparative studies to enhance the understanding of underlying physics of fusion plasmas. The FES program, in return, hosts visiting scientists from the international community for participation in U.S. experiments. The FES program has a long-standing policy of seeking international collaboration. This allows U.S. scientists to have access to the unique capabilities of fusion facilities that exist abroad. These include the world's highest performance tokamak—the Joint European Torus in England, a stellarator—the Large Helical Device in Japan, a superconducting tokamak—Tore Supra in France, AxiSymmetric Divertor Experiment Upgrade and Tokamak Experiment for Technology Oriented Research in Germany, and several smaller devices. In addition, the U.S. is collaborating with China and South Korea on EAST and KSTAR respectively, which have become operational in the past two years. The U.S. collaborations on these two new superconducting tokamaks were instrumental in achieving their first plasmas in September 2006 and June 2008, respectively. These collaborations provide a valuable link with the 80% of the world's fusion research that is conducted outside the U.S. and provide a firm foundation to support ITER activities.

The U.S. is a major participant in the ITPA, which identifies experimental and computational studies to resolve high-priority ITER physics needs and assists in implementation through collaborative experiments among the major international tokamaks, and analysis and interpretation of experiments for extrapolation to ITER.

In FY 2010, the United States will continue to participate in high priority research activities in support of ITER. These include joint ITPA experiments and other joint ITER-relevant experiments in the areas of plasma wall interactions, plasma instabilities, and first wall design considerations for ITER.

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| ▪ **Diagnostics** | **4,141** | **3,962** | **3,912** |

Support for the development of unique measurement capabilities (diagnostic instruments) will continue. Diagnostic instruments serve two important functions: to provide a link between theory/computation and experiments, thereby increasing the understanding of the complex behavior of the plasma in fusion research devices; and to provide sensory tools for feedback control of plasma properties in order to enhance device operation.

In FY 2010, research will include the development of diagnostics for fundamental plasma parameter measurements, state-of-the-art measurement techniques, and R&D for ITER-relevant diagnostic systems. Diagnostic systems will be installed and operated on current experiments in the U.S. and on non-U.S. fusion devices, where appropriate, through collaborative programs.

A competitive peer review of the diagnostics development program will be conducted in FY 2010 for funding that begins in FY 2011.

| | (dollars in thousands) | | |
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| | FY 2008 | FY 2009 | FY 2010 |
| ▪ **Other** | **5,514** | **6,148** | **6,995** |

Funding in this category supports educational activities such as research at historically black colleges and universities, graduate and postgraduate fellowships in fusion science and technology, and summer internships for undergraduates. In addition, funding in this category supports outreach efforts related to fusion science and enabling R&D, operations of the U.S. Burning Plasma Organization and the Fusion Energy Sciences Advisory Committee.

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| **Alternative Concept Experimental Research** | **57,003** | **65,566** | **65,595** |

This program element broadens the fusion program by exploring the science of confinement optimization in the extended fusion parameter space, with plasma densities spanning twelve orders of magnitude, by seeking physics pathways to improve confinement, stability, and reactor configurations. Through this scientific diversity, the program element adds strength and robustness to the overall fusion program by lowering overall programmatic risks in the quest for practical fusion power in the long term, for which economic and environmental factors are important. At present, two alternate concepts are being pursued at the larger-scale, proof-of-principle level. A number of concepts are also being pursued at a concept-exploration level, as well as research in establishing a knowledge base for high energy density plasmas. The smaller scale experiments and the cutting-edge research have proven to be effective in attracting students and strongly contribute to fusion workforce development and the intellectual base of the fusion program. The research has also resulted in new ideas for the larger toroidal devices, including ITER.

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| ▪ **NSTX Research** | **16,293** | **17,387** | **17,399** |

The National Spherical Torus Experiment (NSTX) is one of two large experiments in the world that are exploring the spherical torus (ST) confinement configuration; the other is the MegaAmp Spherical Tokamak (MAST) in the United Kingdom. The spherical torus is an innovative confinement configuration that produces a plasma that is shaped like a sphere with a cylindrical hole through its center. The properties of a ST plasma are different from a conventional tokamak plasma, which is shaped like a donut with a large hole through the center. Results to date indicate that a ST uses applied magnetic fields more efficiently than conventional tokamaks and could, therefore, lead to a cost-effective facility for carrying out the nuclear engineering science research needed to design the power extraction and tritium breeding systems for a fusion energy system.

In FY 2010 the NSTX team will continue a research program designed to provide the physics basis for future ST-based research facilities, contribute to the physics basis for ITER, and advance the fundamental understanding of magnetically confined plasmas. Using new diagnostic capabilities, the NSTX team will perform unique and critical experiments to understand the relation between electron energy confinement and fluctuations in the plasma density and electron temperature. This is an area of critical importance to fusion science and NSTX offers unique capabilities to investigate this topic. Continued study of macroscopic instabilities such as the resistive wall mode and neoclassical tearing mode will focus on developing passive and active control techniques to stabilize these modes. Following the installation of a liquid lithium divertor, boundary physics studies will focus on how reduced recycling affects the properties of the plasma edge. Plasma-wave studies will concentrate on developing a predictive understanding of the redistribution/loss of fast-ions due to energetic particle modes. Research on energetic particle modes will also lead to increased knowledge of how the plasma current density is modified by

| | (dollars in thousands) | | |
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| | FY 2008 | FY 2009 | FY 2010 |

energetic ion driven instabilities and how this will affect the ability to sustain the plasma with currents driven by injected high energy particle beams. Finally, there will be a considerable effort on demonstrating solenoid-free start-up and current ramp-up capabilities that will be needed by future ST devices.

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| ▪ **Experimental Plasma Research** | **17,026** | **16,780** | **16,745** |

Experimental Plasma Research was started to explore Innovative Confinement Concepts (ICC). In the ICC program, a number of small concept-exploration level facilities have been constructed, an ICC-centric theory center has been formed and several small topic-specific investigations have been supported. The facilities built include stellarators, spheromaks, field-reversed configurations, a levitated dipole, a flow-stabilized z-pinch, centrifugally confined magnetic mirrors, and electrostatic confinement. In general, these cover emerging concepts for plasma confinement and stability. These studies have intrinsic value to the plasma science and fusion energy missions of the FES program since they provide unique tests and extensions of our understanding of confined plasmas. In that sense, these programs complement the larger tokamak programs to help establish the predictive understanding of fusion plasma behavior. The program will undergo a peer review in FY 2010, the goal of which is to select a portfolio of concepts to generate sufficient experimental data to elucidate the underlying physics principles upon which these concepts are based and, as needed, to develop computational models of promising concepts to a sufficient degree of scientific fidelity to allow an assessment of the relevance of those concepts to future fusion energy systems.

In FY 2010, experimental plasma research will continue to examine novel three-dimensional confinement systems that address potential deficiencies in the tokamak, and support development of instability mitigation techniques for ITER. Despite the cancellation of the National Compact Stellarator Experiment (NCSX), stellarators remain a top alternative confinement concept that can mitigate several of the potential deficiencies of the tokamak configuration. Research on the stellarator concept will be continued within this program.

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| ▪ **High Energy Density Laboratory Plasmas** | **16,021** | **24,534** | **24,536** |

High energy density laboratory plasma physics is the study of ionized matter at extremely high density and temperature. According to the 2007 National Academies Press report on *Plasma Science—Advancing Knowledge in the National Interest*, high energy density (HED) physics begins when matter is heated or compressed (or both) to a point that the stored energy in the matter reaches approximately 10 billion Joules per cubic meter. This corresponds to a pressure of approximately 100,000 atmospheres. HED conditions exist in the interior of the Sun where hydrogen has been fused to produce energy. Supernovae, gamma ray bursts, accretion disks around black holes, pulsars, and astrophysical jets are examples of HED astrophysical phenomena. On Earth, HED conditions can only be created transiently in the laboratory by using intense pulses of lasers, particle beams (electrons or ions), plasma jets, magnetic pinches, or their combinations. Because of its potentially immense impact on energy security, the National Academies report recommended that SC provide stewardship of HED plasma science related to inertial fusion including the use of magnetized targets.

In FY 2010, the proposed budget will maintain the research at approximately the same level as FY 2009. On-going research include studies of warm dense matter driven by heavy ion beams, fast

| | (dollars in thousands) | | |
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| | FY 2008 | FY 2009 | FY 2010 |

ignition, magnetized high energy density plasmas, and high mach number and high density plasma jets. Funding awards will be determined by competitive peer-review and recommendations from workshops and conferences.

To enhance the study of the field of high energy density matter, FES is building a Matter in Extreme Conditions (MEC) Instrument project at the Stanford Linear Accelerator Laboratory (SLAC) Linac Coherent Light Source (LCLS). LCLS will be the world's state-of-the-art x-ray laser and the MEC project will enable high energy density matter to be probed and controlled by this advanced coherent x-ray source with unprecedented resolution in time and space. Recovery Act funding will be used to completely build the MEC instrument.

| | FY 2008 | FY 2009 | FY 2010 |
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| ▪ **Madison Symmetrical Torus** | **6,910** | **6,865** | **6,915** |

The goals of the Madison Symmetrical Torus (MST) at the University of Wisconsin-Madison are to obtain a fundamental understanding of the physics of reversed field pinches (RFPs), particularly magnetic fluctuations and their macroscopic consequences, and to use this understanding to develop the RFP fusion configuration. The RFP is geometrically similar to a tokamak, but with a much weaker externally applied magnetic field that reverses direction near the edge of the plasma. Research in the RFP's self-organization properties has astrophysical applications and may lead to a more cost-effective fusion system. The plasma dynamics that limit the energy confinement and plasma pressure, as well as novel means to the sustainment of the plasma current, are being investigated in this experiment. MST is one of the four leading RFP experiments in the world and is unique in that it pioneered the reduction of magnetic fluctuations by current density profile control. In recent years, this approach has led to a ten-fold increase in energy confinement time.

In FY 2010, the major plans of the MST program are to begin high power (approximately 1 MW) neutral beam injection experiments and further investigations of electron temperature fluctuations using high rep-rate Thomson scattering. The neutral beam injection will provide key new capability in the investigations of the RFP beta limit, momentum transport, and the confinement and stability of energetic ions.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **NCSX Research** | **753** | **—** | **—** |

Due to the cancellation of the National Compact Stellarator Experiment (NCSX) in May 2008, the NCSX research portion of the program was concluded in FY 2008.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **Theory** | **24,505** | **24,176** | **24,283** |

The Theory program provides the conceptual scientific underpinning of the magnetic fusion energy sciences program by supporting three thrust areas: burning plasmas, fundamental understanding, and configuration improvement. Theory efforts describe the complex multiphysics, multiscale, non-linear plasma systems at the most fundamental level and, in doing so, generate world-class science. These descriptions—ranging from analytic theory to highly sophisticated computer simulation codes—are used to interpret results from current experiments, plan new experiments on existing facilities, design future experimental facilities, and assess projections of facility performance. The program focuses on both tokamaks and alternate concepts. Work on tokamaks is aimed at developing a predictive understanding of advanced tokamak operating modes and burning plasmas—both of which are important to ITER—while the emphasis on alternate concepts is on understanding the fundamental processes determining equilibrium, stability, and confinement for each concept. The theory program also provides the input needed in the FES large-scale simulation efforts that are part of the SciDAC

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |

portfolio and, together with SciDAC, is expected to lead to a predictive understanding of how fusion plasmas can be sustained and controlled.

The Theory program is a broad-based program with researchers located at six national and federal laboratories, over thirty universities, and several private companies. Theorists in larger groups, located mainly at national laboratories and private industry, generally support major experiments, work on large problems requiring a team effort, or tackle complex issues requiring multidisciplinary teams. Those at universities tend to support smaller, innovative experiments or work on more fundamental problems in plasma physics while training the next generation of fusion plasma scientists.

In FY 2010 the Theory Program will focus particular attention on the turbulent transport of toroidal and poloidal momentum in tokamak plasmas and the understanding of spontaneous toroidal rotation; progress toward a predictive understanding of particle and electron transport; the physics of the edge pedestal and the transition from low to the high confinement modes in tokamaks; the formation of edge and internal transport barriers; the first-principles formulation of moment closures in extended magnetohydrodynamics models; the calculation of atomic and molecular collision processes of importance in fusion reactors; the study of how to improve the stellarator concept and find configurations that are less prone to the formation of islands; the study of other innovative confinement concepts; the understanding of fast magnetic reconnection in high temperature fusion plasmas; and the development of predictive integrated computational models for tokamak plasmas.

| | | | |
|---|---|---|---|
| **Advanced Fusion Simulations** | **7,081** | **9,188** | **11,212** |

The FES Advanced Fusion Simulations program includes projects funded under the auspices of the SC Scientific Discovery through Advanced Computing (SciDAC) program as well as a new computational activity focused on integrated modeling, the Fusion Simulation Program (FSP). These two program elements are described in more detail below.

| | | | |
|---|---|---|---|
| ▪ **SciDAC** | **7,081** | **7,212** | **7,212** |

The SciDAC program is a set of coordinated research efforts across all SC programs overseen by the Advanced Scientific Computing Research (ASCR) program with the goal of achieving breakthrough scientific advances through computer simulation that are otherwise impossible using theoretical or laboratory studies alone. By taking advantage of the exponential advances in computing and information technologies as tools for discovery, SciDAC encourages and enables a new model of multi-disciplinary collaboration among physical scientists, mathematicians, computer scientists, and computational scientists. The product of this collaborative approach is a new generation of scientific simulation codes that can fully exploit the emerging capabilities of terascale and petascale computing.

The current FES SciDAC portfolio includes eight projects spanning 29 institutions with 44% of the funding going to national laboratories, 38% going to universities, and 18% going to private industry. Of these, five are focused on single-issue topical science areas, such as macroscopic stability, the simulation of electromagnetic wave-plasma interaction, the study of turbulent transport in burning plasmas, and the physics of energetic particles. In FY 2010, these projects will continue to focus their efforts on grand challenge scientific questions of importance to burning plasmas and ITER emphasizing validation of simulation codes with experimental results.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |

The remaining three projects are known as Fusion Simulation Prototype Centers or proto-FSPs and focus on code integration and computational framework development in the areas of edge plasma transport, interaction of RF waves with MHD, and the coupling of the edge and core regions of tokamak plasmas. In FY 2010, the proto-FSP Centers will continue to focus their efforts on issues important to burning plasmas and ITER such as advancing our understanding of the effects of RF waves on macroscopic instabilities, the development of a first-principles predictive edge pedestal model for ITER, and the development of advanced computational frameworks for integrated fusion simulations.

| | | | |
|---|---|---|---|
| ▪ **Fusion Simulation Program** | **—** | **1,976** | **4,000** |

The Fusion Simulation Program (FSP) is a computational initiative led by FES with collaborative support from ASCR. It is aimed at the development of a world-leading, experimentally validated, predictive simulation capability for fusion plasmas in the regimes and geometries relevant for practical fusion energy. The FSP will take advantage of the emergence of SC petascale computing capabilities and the scientific knowledge enabled by the FES and ASCR research programs, in particular those under the auspices of the SciDAC program. The FSP will contribute significantly toward the FES mission of establishing the scientific basis for fusion energy, as well as its long term goal of developing a predictive capability for burning plasmas. It will also help the U.S. sustain and strengthen its leadership in advanced fusion computations.

In 2007, a national research needs workshop was held to refine the long term vision of the FSP and develop a detailed roadmap. The workshop report was reviewed by the FESAC, which suggested that FES proceed with a detailed planning study for this research program.

In FY 2009, following a successful peer review, FES selected a multi-institutional interdisciplinary team of six national laboratories, nine universities, and two private companies to carry out a two-year detailed planning study for the FSP. The FSP planning team, led by the Princeton Plasma Physics Laboratory, includes scientists with a broad range of expertise in computational, theoretical and experimental plasma science, applied mathematics, computer and computational science, and software engineering. The increase in funding for FY 2010 will enhance the efforts of the FSP planning team, allowing it to complete the detailed planning study of the program by the end of 2010. The results of this study will help FES and ASCR proceed with the full FSP in FY 2011, subject to the results of an independent review at the end of the planning period.

| | | | |
|---|---|---|---|
| **General Plasma Science** | **14,821** | **14,869** | **14,869** |

The General Plasma Science program is directed toward basic plasma science and engineering research. This research strengthens the fundamental underpinnings of the discipline of plasma physics that makes contributions in many basic and applied physics areas. Principal investigators at universities, laboratories, and private industry carry out the research. A critically important element is the education of plasma physicists. Continuing elements of this program are the NSF/DOE Partnership in Basic Plasma Science and Engineering, the Plasma Science Centers (PSCs), the Plasma Physics Junior Faculty Award Program, the General Plasma Science program carried out at the DOE laboratories, and basic plasma physics user facilities at laboratories and universities (sharing costs with NSF where appropriate). The PSCs perform plasma science research in areas of such wide scope and complexity that it would not be feasible for individual investigators or small groups to make

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |

progress. Atomic and molecular data for fusion will continue to be generated and distributed through openly available databases. FES will continue to share the cost with NSF of the multi-institutional plasma physics Frontier Science Center started in FY 2003 and renewed by NSF for five years in FY 2008.

In 2004, two PSCs were established for a period of 5 years at the cost of $11,900,000. These two PSCs are up for renewal in FY 2009. The program is now in the final stage of a competitive peer review of seven applications for centers that would start in FY 2009. The final funding decisions will be made after presentations to a peer review panel in FY 2009. In FY 2010, the second year of funding is provided for the two new PSCs selected through this peer review process.

| | | | |
|---|---|---|---|
| **SBIR/STTR** | **—** | **8,066** | **8,667** |

In FY 2008, $6,353,000 and $762,000 were transferred to the congressionally mandated Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs, respectively. The FY 2009 and FY 2010 amounts are the estimated requirements for the continuation of these programs.

| | | | |
|---|---|---|---|
| **Total, Science** | **155,032** | **172,387** | **176,067** |

**Explanation of Funding Changes**

| | FY 2010 vs FY 2009 ($000) |
|---|---|
| **Tokamak Experimental Research** | |
| ▪ **DIII-D Research** | |
| Increase to DIII-D Research will maintain enhanced data analysis capability for continued code validation coupled to increased operating time. | +116 |
| ▪ **Alcator C-Mod Research** | |
| Small increase to C-Mod Research will maintain research effort at approximately the same level as FY 2009. | +3 |
| ▪ **International Research** | |
| Small increase to International Research will maintain research effort at approximately the same level as FY 2009. | +3 |
| ▪ **Diagnostics** | |
| The decrease in funding will result in a reduced level of effort in one program. | -50 |
| ▪ **Other** | |
| Small increases to a variety of activities for educational/outreach programs and administrative activities in support of the U.S. Burning Plasma Organization. | +847 |
| **Total, Tokamak Experimental Research** | **+919** |

| | FY 2010 vs FY 2009 ($000) |
|---|---|
| **Alternative Concept Experimental Research** | |
| ▪ **NSTX Research** | |
| Small increase to NSTX Research will maintain research effort at approximately the same level as FY 2009. | +12 |
| ▪ **Experimental Plasma Research** | |
| Small decrease to Experimental Plasma Research will maintain research effort at approximately the same level as FY 2009. | -35 |
| ▪ **High Energy Density Laboratory Plasmas (HEDLP)** | |
| Small increase to HEDLP will maintain research effort at approximately the same level as FY 2009. | +2 |
| ▪ **Madison Symmetrical Torus (MST)** | |
| Small increase to MST will maintain research effort at approximately the same level as FY 2009. | +50 |
| **Total, Alternative Concept Experimental Research** | **+29** |
| **Theory** | |
| Small increase to fund the purchase of computer clusters for the theory program. | +107 |
| **Advanced Fusion Simulations** | |
| The increase will accelerate the Fusion Simulation Program planning study initiated in FY 2009 and allow FES to begin the full program in FY 2011 as scheduled. | +2,024 |
| **SBIR/STTR** | |
| Support for SBIR/STTR is funded at the mandated level. | +601 |
| **Total Funding Change, Science** | **+3,680** |

## Facility Operations

### Funding Schedule by Activity

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Facility Operations | | | |
| DIII-D | 34,452 | 36,141 | 38,330 |
| Alcator C-Mod | 15,695 | 15,934 | 17,434 |
| NSTX | 22,274 | 22,975 | 23,400 |
| NSTX Upgrade (MIE) | — | 5,575 | 5,000 |
| NCSX | 15,900 | —[a] | — |
| GPP/GPE/Other | 2,577 | 2,628 | 2,578 |
| U.S. Contributions to ITER (MIE TPC) | 26,070[b] | 124,000 | 135,000 |
| Total, Facility Operations | 116,968 | 207,253 | 221,742 |

## Description

The mission of the Facility Operations subprogram is to provide for the operation, maintenance, and enhancements of the major fusion research facilities—Alcator C-Mod, DIII-D, and NSTX—to meet the needs of the scientific collaborators using the facilities. Periodic facility reviews are used to ensure that the facilities are operated efficiently and in a safe and environmentally sound manner. The major FES facilities enable U.S. scientists from universities, laboratories, and industry, as well as visiting foreign scientists, to conduct world-class research that is funded through the Science and Enabling R&D subprograms. In addition, this subprogram is responsible for the execution of new projects and upgrades of major fusion facilities, such as installation of new diagnostics, in accordance with the highest project management standards and with minimum deviation from approved cost and schedule baselines.

The *DIII-D* tokamak at General Atomics in San Diego, California is the largest magnetic fusion facility in the United States. DIII-D provides for considerable experimental flexibility and has extensive diagnostic instrumentation to measure the properties of high temperature plasmas. It also has unique capabilities to shape the plasma and provide feedback control of error fields that, in turn, affect particle transport and the stability of the plasma.

*Alcator C-Mod* at the MIT is the only tokamak in the world operating at and above the ITER design magnetic field and plasma densities, and it produces the highest pressure tokamak plasma in the world, approaching pressures expected in ITER. It is also unique in the use of all-metal walls to accommodate high power densities. Because of these characteristics, C-Mod is particularly well suited to examine plasma regimes that are highly relevant to ITER.

*NSTX* is an innovative magnetic fusion device at the PPPL using the spherical torus confinement configuration. A major advantage of this configuration is the ability to confine a higher plasma pressure

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[a]Due to cancellation of the NCSX project in May 2008, closeout costs were provided for in FY 2008, and the FY 2009 funding has been reallocated to provide increases in facilities operations and upgrades and experimental plasma research on smaller-scale stellarators.

[b] Starting in FY 2009, the U.S. Contributions to ITER project TEC and OPC funds are consolidated and requested in this subprogram. FY 2008 funding displayed here reflects this change. The FY 2008 budget reflected the FY 2008 OPC costs of $10,626,000 under the Enabling R&D subprogram.

for a given magnetic field strength, which could enable the development of smaller, more economical fusion research facilities.

*ITER* is a critical step between today's facilities designed to study plasma physics and a demonstration fusion power plant. An unprecedented international collaboration of scientists and engineers led to the design of this burning plasma physics experiment. Project partners are China, the European Union (EU), India, Japan, Russia, South Korea, and the United States. ITER is presently under construction in Cadarache, France, with experimental operations planned to begin in approximately 10 years.

As a result of the FY 2009 Appropriations, DIII-D, Alcator C-Mod, and NSTX plan to operate less in FY 2009 than in FY 2008. Recovery Act funding is provided to enhance and increase the facility operations, allowing each facility to conduct a larger number of high priority science experiments. The funding requested in FY 2010 will support operations at 50-60% of the maximum level and provide research time for about 500 scientists from universities, laboratories, and industry.

The *U.S. Contributions to the ITER Project* continues into its fifth year. The FY 2010 Request of $135,000,000 will provide for operation of the U.S. ITER Project Office (USIPO) at Oak Ridge National Laboratory; engineering design, R&D, and long-lead procurements for U.S. hardware components; U.S. personnel seconded to the ITER Organization (IO); and funds to the IO for its common needs such as directly employed IO staff and infrastructure. The scope and schedule of work planned for FY 2010 will also depend on the IO's schedule needs and priorities.

Funding is also included in this subprogram for general plant projects (GPP) and general purpose equipment (GPE) at PPPL. GPP and GPE support essential facility renovations and other necessary capital alterations and additions to buildings and utility systems.

**Selected FY 2008 Accomplishments**

- *Facility operation reviews completed:* In FY 2008 a series of coordinated reviews of the operational efficiency and effectiveness of all three major facilities was conducted. Operational review panels evaluated data, toured the facilities, and received presentations from the facility management. Charged with answering a set of questions pertaining to the cost effectiveness and efficiency of operations at each of the facilities, the panels found that all three are generally well run and provide an excellent set of tools to the U.S. fusion research community.
- *DIII-D:* As a result of FY 2008 activities, the installation of a new high voltage transformer was completed in FY 2009. This upgrade to the site power capability will permit simultaneous operation of all auxiliary heating and current drive systems at full power for the typical DIII-D pulse length.
- *Alcator C-Mod:* A major inspection, which is carried out every five years, was conducted on the Alcator C-Mod facility. The Alcator C-Mod tokamak was disassembled and inspected, and the magnet joints were cleaned and refurbished.
- *NSTX:* Successful operation of dual Lithium evaporators to provide complete toroidal coverage of lithium to the lower divertor structure was accomplished. Plasma performance was improved over the previous experience with one Lithium evaporator, and high-performance operation with no between-shot helium glow discharge cleaning was demonstrated, thus increasing the achievable shot-rate by more than 10%.

## Detailed Justification

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| **DIII-D** | **34,452** | **36,141** | **38,330** |

To carry out the science identified in the previous section, support is provided for operation, maintenance, and improvement of the DIII-D facility and its auxiliary systems. In FY 2010, 14 weeks of single shift plasma operation will be conducted, during which time essential scientific research will be performed as described in the Science subprogram. Operations will continue to support experiments addressing ITER design and operations issues and developing the advanced tokamak concept for fusion energy. Experiments in FY 2010 will take advantage of the recently completed facility power system upgrade, adding the ability to operate all eight neutral beam sources, six high power microwave tubes, and three fast wave heating systems simultaneously if required. After operations are completed in FY 2010 an extended vent period is planned in order to modify one of the neutral beam lines for off-axis injection and add a set of additional inner wall coils to the inside of the DIII-D vessel.

| | | | |
|---|---|---|---|
| Achieved Operating Hours | 758 | N/A | N/A |
| Planned Operating Hours | 758 | 520 | 560 |
| Optimal Hours | 1,000 | 1,000 | 1,000 |
| Percent of Optimal Hours | 75.8% | 52.0% | 56.0% |
| Unscheduled Downtime | 12.3% | N/A | N/A |
| Number of Users | 240 | 220 | 235 |

| | | | |
|---|---|---|---|
| **Alcator C-Mod** | **15,695** | **15,934** | **17,434** |

Support is provided for operation, maintenance, minor upgrades, and improvement of the Alcator C-Mod facility and its auxiliary systems, including completing and installing a second advanced 4-strap ion cyclotron radio frequency antenna, returning to full system capability (8 MW source, at least 6 MW coupled), continued planning for a second advanced lower hybrid launcher (FY 2011 installation), and the design of a DEMO-like high temperature tungsten divertor (FY 2011 installation). In FY 2010, Alcator C-Mod will be operated for 16 weeks, focusing on ITER design and operations issues and addressing high field and density issues.

| | | | |
|---|---|---|---|
| Achieved Operating Hours | 502 | N/A | N/A |
| Planned Operating Hours | 502 | 192 | 512 |
| Optimal Hours | 800 | 800 | 800 |
| Percent of Optimal Hours | 62.8% | 24.0% | 64.0% |
| Unscheduled Downtime | 5.0% | N/A | N/A |
| Number of Users | 193 | 182 | 200 |

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| **NSTX** | **22,274** | **22,975** | **23,400** |

Support is provided for operation, maintenance, and a few facility and diagnostic upgrades on NSTX, including an edge ultra-soft x-ray array, a divertor spectrometer, beam emission spectroscopy for measuring ion-scale turbulence, and an ion flow measurement diagnostic. In FY 2010, there is funding for 15 weeks of operation to explore issues of sustained spherical torus (ST) operation and study ST confinement at high fields relevant to evaluating the science base for high-heat flux and plasma nuclear science initiatives. In FY 2010, NSTX will fully exploit new capabilities added in FY 2009 such as the liquid lithium divertor and the upgraded high harmonic fast wave (HHFW) antenna.

| | | | |
|---|---|---|---|
| Achieved Operating Hours | 665 | N/A | N/A |
| Planned Operating Hours | 665 | 440 | 640 |
| Optimal Hours | 1,000 | 1,000 | 1,000 |
| Percent of Optimal Hours | 66.5% | 44.0% | 64.0% |
| Unscheduled Downtime | 7.3% | N/A | N/A |
| Number of Users | 150 | 140 | 145 |

| | | | |
|---|---|---|---|
| **NSTX Upgrade (MIE)** | **—** | **5,575** | **5,000** |

Support is provided to begin conceptual design work for a major upgrade of NSTX to keep its world-leading status. A new centerstack magnet assembly that will double the magnetic field and a second neutral beam (NB) line that will double the NB power into heating the plasma are both being considered. The proposed funding and Critical Decision (CD) schedule for these activities will be refined in FY 2010. A final decision as to which upgrades to proceed with will be made at CD-2.

| | | | |
|---|---|---|---|
| **NCSX** | **15,900** | **—** | **—** |

This project was initiated in FY 2003 and consisted of the design and fabrication of a compact stellarator proof-of-principle class experiment and was terminated in May 2008. There was no funding required in FY 2009; all closeout activities were funded using the FY 2008 appropriation for NCSX. The FY 2009 funding for the NCSX MIE and NCSX Research was redistributed within the FES program to the operations and upgrades of DIII-D, C-Mod, and NSTX ($16,823,000), and for other smaller stellarator research efforts ($3,429,000).

| | | | |
|---|---|---|---|
| **GPP/GPE/Other** | **2,577** | **2,628** | **2,578** |

These funds are provided primarily for general infrastructure repairs and upgrades for the PPPL site based upon quantitative analysis of safety requirements, equipment reliability, and research needs.

| | | | |
|---|---|---|---|
| **U.S. Contributions to ITER Project** | **26,070** | **124,000** | **135,000** |

**Background:** The U.S. ITER Project is the U.S. share of a seven-member international collaboration to design and build a first-of-a-kind international research facility in Cadarache, France to demonstrate the scientific feasibility of fusion energy. The U.S. ITER Project scope consists of delivering hardware components, personnel, and funds to the ITER Organization (IO). The legal framework for construction, operation, deactivation, and decommissioning is contained in the *Agreement on the Establishment of the ITER International Fusion Energy Organization for the Joint Implementation of the ITER Project* (or the JIA), which entered into force in October 2007 for a period of 35 years.

While significant technical progress has been made with large fusion experiments around the world, most of which were constructed in the 1980s, it has long been obvious that a larger and more powerful magnetic confinement device would be needed to create the physical conditions expected in a fusion power plant (i.e., a sustained "burning plasma" comprised of hot ionized deuterium and tritium gas) and to demonstrate its feasibility. The idea to cooperatively design and build such a device originated from a Geneva superpower summit in November 1985 where Soviet Premier Gorbachev proposed to President Reagan that an international project be set up to develop fusion energy for peaceful purposes. The U.S. participated in the initial design activity, and after a hiatus, the U.S. joined the ITER negotiations in early 2003.

U.S. membership in ITER complies with provisions of the Energy Policy Act of 2005 (EPAct 2005), Section 972(c)(5)(C) which required that DOE provide Congress with three reports: a "Plan for U.S. Scientific Participation in ITER", a report describing the management structure of ITER and estimate of the cost of U.S. participation, and a report describing how U.S. participation in ITER will be funded without a funding reduction in other SC programs. The National Research Council also reviewed (and endorsed) the Plan for Scientific Participation in ITER, as required by EPAct.

**International ITER Project Status:** The IO, located at Cadarache, has been established as an independent international legal entity comprised of personnel from all of the Members. The IO is led by a Director General who is appointed by the ITER Council, which serves as ITER's executive governing board. The Council is comprised of representatives from all the Members. Like all non-host Members, the U.S. share for ITER's construction is 1/11 (9.09%) of the total value estimate—roughly 80% will be in-kind components manufactured by U.S. industry—and beyond that, the U. S. has agreed to fund 13% of the cost for operation, deactivation, and decommissioning. As the Host, the EU is obligated to provide 5/11 (45.45%) of ITER's construction value. The JIA identifies the hardware procurement allocations among the seven Members based on this cost sharing arrangement. Starting from literally a "green field" site in 2006, the ITER enterprise at Cadarache had staffed up to roughly half of its full complement of 700 personnel by the end of 2008.

An international design review in 2007 recommended several important ITER design improvements and identified some missing items of scope, such as certain test facilities and a number of spare parts. In 2008, the first bottoms-up Integrated Project Schedule was developed for the Construction Phase. Although the JIA included a goal for construction completion and first plasma to be achieved in 2016, this appears certain to slip. Together with other factors, these developments have served to drive up the estimate for ITER's construction cost. Indeed, the IO's most urgent tasks at present are to complete work on the overall ITER design and systems engineering and establish realistic schedule and cost baselines. While the ITER Council has asked the IO to accomplish these efforts by late 2009 and has commissioned an independent cost review panel to evaluate the IO's cost estimates, it appears that this milestone will not be met. The U. S. will continue to emphasize the importance of completing these efforts and provide support as needed.

At its June 2008 meeting, the ITER Council established the Export Control Working Group (ECWG) to provide advice on the establishment of ITER policies and procedures for export control, peaceful uses, and non-proliferation. These administrative processes must be consistent with the primacy of each Member's export control regulations, and at the same time prevent export-control-driven delivery delays of hardware and technology. To date, policies and strategies for implementation have been drafted by the ECWG for presentation at the June 2009 ITER Council Meeting.

The U. S. has consistently insisted on project management excellence in all aspects of ITER in order to minimize cost and schedule risk.

**U.S. ITER Project Status:** The main cost risk to the U.S. ITER Project is the slow rate of progress by the IO in specifying design requirements and in design integration, which in turn is hindering design completion and extending the schedule. Next, there remains some ambiguity in the impact of EU/French nuclear regulatory requirements on U.S. hardware designs. Development of a realistic ITER baseline schedule and cost estimate is ongoing. Once the baseline has been established and approved by the Council, the USIPO will be able to develop schedule and cost baselines for the U.S. ITER Project scope in preparation for CD-2, Approve Performance Baselines. CD-2 is currently projected to occur in late FY 2010 or FY 2011.

Research activities in the domestic fusion program continue to enhance the physics basis and technology support for ITER. While these activities are of general interest to developing the underlying knowledge base for fusion energy, they synergistically support the move to science research on ITER in the future by:

- Providing R&D on ITER physics and technology issues and exploring new modes of operation to enhance ITER performance;
- Developing safe and environmentally attractive technologies relevant to ITER;
- Advancing fusion simulation as a tool to examine the complex behavior of burning plasmas in tokamaks, which will impact the planning and conduct of experimental operations in ITER;
- Conducting experiments on domestic science facilities to develop diagnostics and plasma control techniques that can be extrapolated to ITER; and
- Integrating all that is learned into a forward-looking approach to future fusion applications.

**Estimated ITER TPC Range:** The TPC range approved at CD-1 represents the magnitude of the cost risks that remained at the time it was developed in late 2007. It preceded, and thus did not account for, the impact of the FY 2008 Energy and Water Development and Related Agencies Appropriations Act. The sources of potential cost growth can be categorized as follows: U.S. funding shortfalls actions taken by the ITER Council and the IO external factors outside of DOE's control and design maturity.

Among the aspects under the IO’s purview, the principal cost drivers are the overall project schedule, design changes and other actions affecting hardware scope and manufacturing costs, as well as French and EU licensing/regulatory requirements. The IO is continuing to develop an integrated baseline schedule for the Construction Phase that includes detailed inputs from the seven Members. Likewise, there are several changes to the reference design to be implemented in 2009, some of which may increase the U.S. ITER TPC.

External factors include changes in Dollar/Euro exchanges rates, escalation rates, commodity prices, and market conditions for hardware procurement. The JIA requires funding contributions from the Members to be made in Euros, which has already increased U.S. ITER Project costs due to increases in the Dollar-Euro exchange rates. Prices for raw materials used in manufacturing U.S. supplied hardware have also been steadily increasing. Although prices have moderated in recent months, this remains a significant concern.

Finally, the reference design for ITER is not complete in certain areas such as the first wall and shield system, for which the U.S. has some manufacturing responsibility. This means that there could be adverse cost impacts as the design is finalized prior to fabrication. A Test Blanket Module (TBM) program has been envisioned as a means to demonstrate a key element of fusion technology, namely the breeding of tritium for a closed fuel cycle in a fusion power plant. While not part of the construction scope of ITER it will have near-term financial implications since certain modifications to the currently designed ITER civil infrastructure must be made to accommodate TBMs. The U.S. share of these modifications is expected to be modest (under $10,000,000) and will be funded by the U.S. ITER Project.

All of these risks were previously evaluated to develop a TPC range for CD-1. It was determined that the bottom of the range should be set at $1.45 billion, which included a reasonable contingency amount (equal to 27 percent of the hardware cost). The difference between $1.45 billion and the top end of the TPC range, $2.2 billion, essentially provides additional contingency for known risks in the above categories as well as an amount for unidentified risks.

**ITER Financial Schedule**

**Total Project Cost (TPC)**[a]

(budget authority in thousands)

| Fiscal Year | Total Estimated Cost | Other Project Costs | Total Project Costs |
|---|---|---|---|
| 2006 | 15,866 | 3,449 | 19,315 |
| 2007 | 42,000 | 18,000 | 60,000 |
| 2008 | 22,500 | 3,570 | 26,070 |
| 2009 | 109,000 | 15,000 | 124,000 |
| 2010 | 105,000 | 30,000 | 135,000 |
| Outyears | TBD | TBD | TBD |

In FY 2009, the $124,000,000 appropriation will be used to resume the full range of U.S. responsibilities in ITER. U.S. activities will focus on material bonding R&D for first wall components; design and analysis of the central solenoid magnet structure, first wall and shield, port limiters, tokamak cooling water system, fueling pellet injector, tokamak exhaust processing system, ion and electron cyclotron heating transmission lines, and diagnostics; and initiating long-lead procurements of toroidal field magnet conductor materials, tokamak cooling water system components, and first articles of the first wall and shield modules. In addition, the funds will be used to support the USIPO, provide U.S. secondees to the IO, and provide funding contributions to the IO per the terms of the JIA.

In FY 2010, the $135,000,000 requested will be used to continue the R&D and design activities described above. Funds will also be used to support the USIPO and U.S. secondees at the IO, as well as provide funding contributions to the IO per the terms of the JIA.

[a]A complete baseline funding profile, including the outyears, will be established at CD-2, which is anticipated to be in late FY 2010 or FY 2011.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| | (dollars in thousands) | | |

**ITER Related Annual Funding Requirements:** The current estimate in the table below incorporates the terms of the JIA on cost sharing during operations, deactivation and decommissioning. Specifically, it considers the procedure for converting currencies into Euros and the 20-year period of annual contributions to the decommissioning fund in conjunction with ITER operations.

| (dollars in thousands) | Current Estimate | Previous Estimate |
|---|---|---|
| FY 2015–FY 2034[a] | | |
| U.S. share of annual facility operating costs including commissioning, maintenance, repair, utilities, power, fuel, improvements, and annual contribution to decommissioning fund for the period 2015 to 2034. Estimate is in year 2015 dollars. | 80,000 | 80,000 |
| FY 2035–FY 2039 | | |
| U.S. share of the annual cost of deactivation of ITER facility for the period 2035–2039. Estimate is in year 2037 dollars. | 25,000 | 25,000 |

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **Total, Facility Operations** | **116,968** | **207,253** | **221,742** |

## Explanation of Funding Changes

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| **DIII-D** | |
| The increase in funding for FY 2010 will allow for an increase in the weeks of operation from 13 in FY 2009 to 14 in FY 2010. It will also support the initiation of the modification of one beam line for off-axis injection and installation of a new inner coil set. | +2,189 |
| **Alcator C-Mod** | |
| The increase in funding for FY 2010, along with the completion of major maintenance activities which limited operations in FY 2009, will allow an increase in the weeks of operation from 6 in FY 2009 to 16 in FY 2010. | +1,500 |
| **NSTX** | |
| The increase in funding for FY 2010 will allow for an increase in the weeks of operation from 11 in FY 2009 to 16 in FY 2010. It will also support several diagnostic upgrades and full exploitation of the new liquid lithium divertor. | +425 |

[a] These estimates will be updated to reflect a more realistic start date for the ITER Operations Phase once the ITER Council has approved a baseline schedule for the Construction Phase.

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| **NSTX Upgrade (MIE)**<br>A small decrease in funding for FY 2010 will maintain the effort at approximately the same level as FY 2009. | -575 |
| **GPP/GPE/Other**<br>A small decrease in funding for FY 2010 will maintain the effort at approximately the same level as FY 2009. | -50 |
| **U.S. Contributions to ITER Project**<br>This funding change provides for the fifth year of project funding. Activities in FY 2010 will mainly focus on advancing and/or completing various U.S. hardware component designs and supporting R&D activities, as well as long-lead procurements for major U.S. components. | +11,000 |
| **Total Funding Change, Facility Operations** | **+14,489** |

## Enabling R&D

### Funding Schedule by Activity

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Enabling R&D | | | |
| Engineering Research | 17,183 | 18,119 | 17,974 |
| Materials Research | 5,750 | 4,791 | 5,217 |
| Total, Enabling R&D | 22,933 | 22,910 | 23,191 |

### Description

The Enabling R&D subprogram helps the Science subprogram address its scientific challenges by developing, and continually improving, the hardware, materials, and technology that are incorporated into existing fusion research facilities, thereby enabling these facilities to achieve higher levels of performance within their inherent capability. Enabling R&D efforts provide both evolutionary development advances in present day capabilities that make it possible to enter new plasma experimental regimes, such as burning plasmas, and nearer-term technology advancements enabling international technology collaborations that allow the U.S. to access plasma experimental conditions not available domestically. In addition, the Enabling R&D subprogram supports the development of new hardware, materials and technology that are incorporated into the design of next generation facilities, thereby increasing confidence that the predicted performance of these new facilities will be achieved.

The Engineering Research element addresses the breadth and diversity of domestic interests in enabling R&D for magnetic fusion systems as well as international collaborations with emphasis on plasma heating, fueling, and surface protection technologies. While much of the effort is focused on current devices, a significant and increasing amount of the research is oriented toward the technology needs or issues that will be faced in future experiments, including ITER. An example would be to understand scientifically what is occurring in a burning plasma with material erosion and redeposition within the fusion chamber caused by this harsh environment and what effect it can have on the plasma and ITER operation. In addition to providing the tools that help accomplish the experimental research, a part of this element also conducts system studies of the most scientifically challenging concepts for fusion research facilities that may be needed in the future as well as identifying critical scientific issues and missions for the next stage in the FES program. Finally, analysis and studies of critical scientific and technological issues are supported, the results of which will provide guidance for optimizing future experimental approaches and for understanding the implications of fusion research on applications of fusion.

The Materials Research element focuses on the key science issues of materials for practical and environmentally attractive uses in fusion research and future facilities. This element uses both experimental and modeling activities, which makes it more effective at using and leveraging the substantial work on nanosystems and computational materials science being funded by other programs, as well as making it more capable of contributing to broader research in niche areas of materials science. The long-term goal of this element is to develop experimentally validated predictive and analytical tools that can lead the way to nanoscale design of advanced fusion materials with superior performance and lifetime.

In FY 2010, research efforts will continue supporting the development of enabling technologies that enhance plasma performance and address fusion engineering science issues for both current and planned domestic and international machines. Resources will be used to continue to develop a scientifically-validated database for materials that can be used in future facilities and to address potential issues that may occur during ITER operation. In addition, a small, but joint materials initiative will begin with the Offices of Basic Energy Sciences (BES) and Advanced Scientific and Computing Research (ASCR) to address the significant challenges of materials under extreme environments like those posed by fusion.

**Selected FY 2008 Accomplishments**

- *Discovery of a New Atomic Diffusion Mechanism in Materials:* Materials science research has uncovered a new atomic diffusion mechanism in materials. All crystalline materials contain point defects such as vacant lattice sites (vacancies) and atoms that are misplaced off normal lattice sites (interstitials). Much higher than normal concentrations of these defects are created during irradiation, and they typically migrate by a random process. Researchers' observation of a material during testing discovered that nanometer-sized clusters of lattice vacancies exhibited fast migration. Harnessing this migration mode may permit new control of defects which in turn will allow the development of better materials for many different commercial applications.
- *Deployment of a High Power Density ITER-Like Ion Cyclotron Heating Antenna:* A high power prototype of an ITER-Like Antenna (ILA) was built and successfully tested in the U.S. prior to installation on JET. During the testing, the ILA prototype exceeded its performance requirements. In addition, the ILA has been designed to withstand disruptive events that can occur near the plasma edge and still provide the required heating for the plasma. In an upcoming experimental campaign, the ILA will be installed on JET as a demonstration of its full capability and as a test for a future system on ITER.
- *Understanding Tritium Co-Deposition in Plasma Facilities:* Tritium retention in ITER and future fusion devices, which is an important operational and safety issue, will likely be dominated by tritium trapped in co-depositing material. Because of the intensity of the burning plasma in ITER, material inside the plasma chamber can erode from its original place of origin and deposit in other places inside the chamber. After a series of experiments on U.S. facilities, a better understanding of the situation has been developed and it is now possible to make much more accurate predictions of tritium accumulation rates at various locations throughout the ITER vessel.

## Detailed Justification

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| **Engineering Research** | **17,183** | **18,119** | **17,974** |
| ▪ **Plasma Technology** | **14,540** | **13,851** | **13,651** |

Plasma Technology efforts will focus resources on developing enabling technologies for current and future machines, both domestically and internationally, and on addressing potential ITER operational issues in the area of safety and plasma materials interactions. In addition, we will continue our collaborative program with Japan (Tritium Irradiation Thermofluid American-Japanese Network, TITAN) on plasma facing and blanket materials for use in future experiments.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| | (dollars in thousands) | | |

In FY 2010, the following specific activities will be supported:

- Continue the experimental studies and modeling activities of tungsten-carbon-beryllium mixed materials layer formation and redeposition in the University of California at San Diego PISCES facility and in the Tritium Plasma Experiment at Idaho National Laboratory (INL). Results will be applied to evaluate tritium accumulation in plasma facing components that will occur during ITER operation.

- Continue a series of material science experiments under the TITAN cost-sharing collaboration with Japan in the Safety and Tritium Applied Research Facility at INL to resolve key issues of tritium behavior in materials proposed for use in fusion systems.

Besides the above activities, research will be conducted on plasma facing components, heating technologies, and blanket concepts that could be tested in ITER. In addition, this category funds research in safety and plasma-surface interaction and modeling that support addressing potential issues that could be encountered during operation of ITER or future devices.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ **Advanced Design** | **2,643** | **4,268** | **4,323** |

In FY 2010 this effort will continue to focus on system studies by a team of individuals drawn from throughout the fusion research community that have a wealth of experience in fusion science, technology, and facilities. The team is known for its objective approach and its ability to develop highly innovative solutions. In the past the team has conducted studies of various types of fusion devices to help the program identify the R&D necessary to move the program forward.

Using this existing team and other resources, the FES program will initiate a series of strategic planning/scoping studies as follow-on to its June 2009 Research Needs Workshop on the Magnetic Fusion Energy Sciences part of the program. These studies will help identify possible approaches for the next stage in the U.S. fusion research program in the ITER era. The long-term objective is to identify potential initiatives and facilities that may be pursued at the pre-conceptual level.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **Materials Research** | **5,750** | **4,791** | **5,217** |

Materials Research remains the key element in establishing the scientific foundations for safe and environmentally attractive uses of fusion as well as providing solutions for materials issues faced by other parts of the FES program. The FY 2010 request will maintain a Materials Research program that addresses material needs for nearer and longer term fusion devices. The funding will be used for both modeling and experimental activities aimed at the science of materials behavior in fusion environments, including research on candidate materials for the structural elements of fusion chambers. Through a variety of cost-shared international collaborations, this element conducts irradiation testing of candidate fusion materials in the simulated fusion environments of fission reactors to provide data for validating and guiding the development of models for the effects of neutron bombardment on the microstructural evolution, damage accumulation, and property changes of fusion materials.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **Total, Enabling R&D** | **22,933** | **22,910** | **23,191** |

## Explanation of Funding Changes

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| **Engineering Research** | |
| ▪ **Plasma Technology** | |
| The decrease will reduce activities on high temperature superconducting magnet technology. | -200 |
| ▪ **Advanced Design** | |
| The increase will support a series of strategic planning/scoping studies. | +55 |
| **Total, Engineering Research** | -145 |
| **Materials Research** | |
| The increase is the FES part of a joint initiative with ASCR and BES on materials under extreme environments such as fusion. | +426 |
| **Total Funding Change, Enabling R&D** | **+281** |

## Supporting Information

### Operating Expenses, Capital Equipment and Construction Summary

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Operating Expenses | 247,767 | 286,023 | 309,503 |
| Capital Equipment | 45,289 | 114,559 | 109,529 |
| General Plant Projects | 1,877 | 1,968 | 1,968 |
| Total, Fusion Energy Sciences | 294,933 | 402,550 | 421,000 |

### Funding Summary

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Research | | | |
| National Laboratories | 76,709 | 77,022 | 77,176 |
| Universities | 69,732 | 69,775 | 69,344 |
| Industrial | 28,837 | 27,671 | 27,081 |
| Other | 2,687 | 12,763 | 16,990 |
| SBIR and STTR | — | 8,066 | 8,667 |
| Total Research | 177,965 | 195,297 | 199,258 |
| Scientific User Facilities Operations | 72,421 | 75,050 | 79,164 |
| Major Items of Equipment | 41,970 | 129,575 | 140,000 |
| Other (GPP, GPE and Infrastructure) | 2,577 | 2,628 | 2,578 |
| Total, Fusion Energy Sciences | 294,933 | 402,550 | 421,000 |

### Scientific User Facilities Operations and Research

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| DIII-D | | | |
| Operations | 34,452 | 36,141 | 38,330 |
| Facility Research | 27,451 | 26,488 | 26,604 |
| Total DIII-D | 61,903 | 62,629 | 64,934 |
| Alcator C-Mod | | | |
| Operations | 15,695 | 15,934 | 17,434 |
| Facility Research | 9,502 | 9,027 | 9,030 |
| Total Alcator C-Mod | 25,197 | 24,961 | 26,464 |

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| NSTX | | | |
| Operations | 22,274 | 22,975 | 23,400 |
| Facility Research | 16,293 | 17,387 | 17,399 |
| Total NSTX | 38,567 | 40,362 | 40,799 |
| Scientific User Facilities Operations and Research | | | |
| Operations | 72,421 | 75,050 | 79,164 |
| Facility Research | 53,246 | 52,902 | 53,033 |
| Total Scientific User Facilities Operations and Research | 125,667 | 127,952 | 132,197 |

## Facility Users and Hours

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| DIII-D National Fusion Facility | | | |
| Achieved Operating Hours | 758 | N/A | N/A |
| Planned Operating Hours | 758 | 520 | 560 |
| Optimal Hours | 1,000 | 1,000 | 1,000 |
| Percent of Optimal Hours | 75.8% | 52.0% | 56.0% |
| Unscheduled Downtime | 12.3% | N/A | N/A |
| Number of Users | 240 | 220 | 235 |
| Alcator C-Mod | | | |
| Achieved Operating Hours | 502 | N/A | N/A |
| Planned Operating Hours | 502 | 192 | 512 |
| Optimal Hours | 800 | 800 | 800 |
| Percent of Optimal Hours | 62.8% | 24.0% | 64.0% |
| Unscheduled Downtime | 5.0% | N/A | N/A |
| Number of Users | 193 | 182 | 200 |
| National Spherical Torus Experiment | | | |
| Achieved Operating Hours | 665 | N/A | N/A |
| Planned Operating Hours | 665 | 440 | 640 |
| Optimal Hours | 1,000 | 1,000 | 1,000 |
| Percent of Optimal Hours | 66.5% | 44.0% | 64.0% |
| Unscheduled Downtime | 7.3% | N/A | N/A |
| Number of Users | 150 | 140 | 145 |

## Summary Major Items of Equipment

(dollars in thousands)

| | Prior Years | FY 2008 | FY 2009 | FY 2010 | Out Years | Total |
|---|---|---|---|---|---|---|
| MIEs | | | | | | |
| NCSX | | | | | | |
| TEC | 74,159 | 15,900 | — | — | — | 90,059 |
| OPC | 9,570 | — | — | — | — | 9,570 |
| TPC | 83,729 | 15,900 | — | — | — | 99,629 |
| NSTX Upgrade | | | | | | |
| TEC | — | — | TBD | TBD | TBD | TBD |
| OPC | — | — | TBD | TBD | TBD | TBD |
| TPC | — | — | 5,575 | 5,000 | TBD | TBD |
| ITER | | | | | | |
| TEC | 57,866 | 22,500 | 109,000 | 105,000 | TBD | TBD |
| OPC | 21,449 | 3,570 | 15,000 | 30,000 | TBD | TBD |
| TPC | 79,315 | 26,070 | 124,000 | 135,000 | TBD | TBD |
| Total MIEs | | | | | | |
| TEC | | 38,400 | TBD | TBD | | |
| OPC | | 3,570 | TBD | TBD | | |
| TPC | | 41,970 | 129,575 | 140,000 | | |

### Facility Operations MIEs:

- ***National Compact Stellarator Experiment (NCSX)***

  Funding for NCSX Research ($692,000) and NCSX MIE Project ($19,560,000) was included in FY 2009. Due to cancellation of the project in May 2008, closeout costs were provided for in FY 2008, and the FY 2009 funding was redirected to provide increases in facilities operations and upgrades ($16,823,000) and experimental plasma research on smaller-scale stellarators ($3,429,000).

- ***National Spherical Torus Experiment Upgrade Major Item of Equipment Project***

  The NSTX Upgrade Project is being initiated in FY 2009 to support major upgrades at NSTX to keep its world-leading status. The upgrade will add a new centerstack magnet assembly that will double the magnetic field, and a second neutral beam (NB) line that will double the NB power into heating the plasma. CD-0 (Approve Mission Need) was completed on February 23, 2009. The proposed funding and Critical Decision (CD) schedule for these activities will be better defined at CD-1, which is planned for the first quarter of FY 2010. A final decision on upgrades will be made at CD-2.

- ***U.S. Contributions to ITER***

  The objective of the U.S. ITER Project is to deliver the U.S. share of the hardware components, personnel, and funding contributions (in Euros) to the ITER Organization (IO) for the ITER Construction Phase per the terms of the ITER Joint Implementation Agreement that was signed in November 2006. It is being managed by the U.S. ITER Project Office (USIPO), located at Oak

Ridge National Laboratory (ORNL). ORNL serves as the prime contractor to DOE, working with its partners Princeton Plasma Physics Laboratory and Savannah River National Laboratory. Each laboratory has been assigned a well-defined portion of the project's scope that takes advantage of their respective technical strengths. DOE serves as the U.S. Domestic Agency for ITER, and under its direction, the USIPO has responsibility for planning, managing, and delivering the entire scope of the U.S. ITER Project. All U.S. ITER Project activities are being overseen by a DOE Federal Project Director at the DOE Oak Ridge Office. As the design agent and eventual operator/owner of the ITER facility, the IO is responsible for specifying top level hardware design requirements and delivery schedules.

The U.S. ITER Project was formally initiated in July 2005 when Critical Decision 0 (CD-0), Mission Need, was approved by the DOE Senior Acquisition Executive, and the first year of project funding was FY 2006. CD-1, Alternative Selection and Cost Range (including authorization for long-lead procurements), was subsequently approved in January 2008. This set the Total Project Cost (TPC) range at $1.45 to 2.2 billion (as spent). This, however, did not take into account the FY 2008 Energy and Water Development and Related Agencies Appropriations Act that reduced the President's FY 2008 Budget Request from $160,000,000 to $10,626,000. A schedule range for U.S. ITER Project completion (CD-4) was set at FY 2014–2017. Current efforts are focused on completing U.S. hardware component designs and supporting R&D, and assisting the IO with establishing a functionally mature project management organization.

### Scientific Employment

| | FY 2008 actual | FY 2009 estimate | FY 2010 estimate |
|---|---|---|---|
| # University Grants | 246 | 236 | 246 |
| # Laboratory Projects | 167 | 154 | 167 |
| # Permanent Ph.D's (FTEs) | 722 | 720 | 723 |
| # Postdoctoral Associates (FTEs) | 113 | 112 | 113 |
| # Graduate Students (FTEs) | 326 | 325 | 327 |
| # Ph.D.'s awarded | 36 | 37 | 42 |

## Science Laboratories Infrastructure

## Funding Profile by Subprogram

(dollars in thousands)

| | FY 2008 Current Appropriation | FY 2009 Original Appropriation | FY 2009 Additional Appropriation[a] | FY 2010 Request |
|---|---|---|---|---|
| Science Laboratories Infrastructure | | | | |
| Infrastructure Support | 15,287 | 31,308 | +103,873 | 6,599 |
| Construction | 51,574 | 114,072 | +94,241 | 127,001 |
| Total, Science Laboratories Infrastructure | 66,861 | 145,380 | +198,114 | 133,600 |

**Public Law Authorizations:**
Public Law 95–91, “Department of Energy Organization Act”, 1977
Public Law 109–58, “Energy Policy Act of 2005”
Public Law 110–69, “America COMPETES Act of 2007”

## Program Overview

### Mission

The mission of the Science Laboratories Infrastructure (SLI) program is to support scientific and technological innovation at Office of Science (SC) laboratories by funding and supporting mission-ready infrastructure and fostering safe and environmentally responsible operations. Paramount among these is the provision of infrastructure necessary to ensure world leadership by the SC national laboratories in the area of basic scientific research now and in the future. The SLI program also supports SC stewardship responsibilities for over 24,000 acres of the Oak Ridge Reservation (ORR) and the Federal facilities in the town of Oak Ridge, and provides Payments in Lieu of Taxes (PILT) to local communities around ANL, BNL, and ORNL.

### Background

The infrastructure of our national laboratories is aging, with nearly half of active facility space 40 years old or older. This infrastructure includes multiprogram research laboratories, administrative and support buildings, as well as cafeterias, power plants, fire stations, utilities, roads, and other structures. Together, the SC laboratories have over 1,500 operational buildings and real property trailers, with nearly 20 million gross square feet of space. Over 8,500 employees and users of SC research facilities are housed in wooden buildings, trailers, or buildings that are more than 50 years old.

Despite past investments, many SC laboratory facilities and utility systems are not adequate to support the scientific mission because they do not meet the requirements of modern research. Significant work is needed to revitalize SC laboratory infrastructure, and SC has begun to implement an Infrastructure Modernization Initiative that will provide capital investment through the SLI program to make the needed improvements to general infrastructure. These investments will revitalize our ten laboratories over the next ten years. The goals of the Infrastructure Modernization Initiative are to:

[a] The Additional Appropriation column reflects the planned allocation of funding from the American Recovery and Reinvestment Act of 2009, P.L. 111–5. See the Department of Energy Recovery website at http://www.energy.gov/recovery for up-to-date information regarding Recovery Act funding.

- Provide the modern laboratory infrastructure needed to deliver advances in science our Nation requires to remain competitive in the 21st century, and
- Correct longstanding deficiencies while ensuring laboratory infrastructure provides a safe and quality workplace.

The Infrastructure Modernization Initiative currently includes a portfolio of approximately 35 projects across all ten SC laboratories that will provide modern laboratory space, renovate space that does not meet research needs, replace facilities that are no longer cost effective to renovate or operate, modernize utility systems to prevent failures and ensure efficiency, and/or remove excess facilities to allow safe and efficient operations. The completion of these projects is critical to ensuring the continued mission readiness of SC laboratories. Mission readiness of a laboratory's facilities and infrastructure is the capability of those assets to effectively support the scientific mission assigned to the laboratory. The current and future mission readiness of each SC laboratory is evaluated using a peer-reviewed process which focuses on the ability of each laboratory infrastructure element to meet the needs of scientific research.

To execute and manage the Infrastructure Modernization Initiative effectively, the SLI program uses the SC Annual Laboratory Plans. The Annual Laboratory Plans integrate scientific planning with infrastructure/operational planning by directly tying proposed investments to identified mission capability gaps. The plans provide a clear picture of the mission readiness of each laboratory, the capability gaps, and the investments necessary to fill those gaps. The investments proposed form the basis for projects included in the Initiative.

**Subprograms**

The first subprogram of the SLI budget, Infrastructure Support, provides operating funds for the cleanup and removal of excess facilities at SC laboratories and for SC stewardship and Payment in Lieu of Taxes responsibilities. The second subprogram, Construction, includes investments under the Infrastructure Modernization Initiative.

**Budget Overview**

The primary focus of the SLI budget is the ongoing Infrastructure Modernization Initiative whose purpose is to ensure mission readiness of SC laboratories. An increase in the Construction subprogram is included in this request to reflect SC's plan to continue to implement this initiative. The proposed level will continue ongoing projects and will initiate three new projects.

Funding for Excess Facilities Disposition (EFD) projects other than the Bevatron was discontinued in FY 2009 because projects funded under the Infrastructure Modernization Initiative will, in many cases, include funds for removal of aged and outdated facilities that are being replaced by new ones. Other small facility decontamination and decommissioning and cleanup projects not included in the Modernization Initiative will be funded with laboratory overhead. With final funding of the Bevatron in FY 2009, funding for the EFD activity has now been discontinued.

The SLI program received additional funding in FY 2009 provided under the Recovery Act. This funding is being used to accelerate funding to four laboratory modernization projects, allowing construction to proceed more efficiently, minimizing the constraints of a protracted funding profile and providing mission ready facilities more quickly. Recovery Act funds are also being used to accelerate funding for General Plant Project improvements with a total cost of $10,000,000 or less to facilities and infrastructure at multi-program laboratories. The Department of Energy Recovery Act website (http://www.energy.gov/recovery) contains up to date information on Recovery Act funding.

## Infrastructure Support

### Funding Schedule by Activity

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Infrastructure Support | 15,287 | 31,308 | 6,599 |

### Description

The Infrastructure Support subprogram provides operating funds for the cleanup and removal of excess facilities at SC laboratories, SC stewardship responsibilities for over 24,000 acres of the Oak Ridge Reservation (ORR) and the Federal facilities in the town of Oak Ridge, and Payments in Lieu of Taxes (PILT) to local communities around ANL, BNL, and ORNL.

### Selected FY 2008 Accomplishments

- The Building 51 and Bevatron Demolition Project at Lawrence Berkeley National Laboratory will eliminate a legacy accelerator which ceased operation in 1993, freeing up approximately three acres of much needed land at the site for programmatic use. In FY 2008, the contract for this demolition project was awarded significantly below project estimates and demolition was started.
- Funding in the Infrastructure Support subprogram also allowed SC to successfully demolish more than 17,000 square feet of lightly contaminated excess facility space at Argonne and Oak Ridge National Laboratories in FY 2008.

### Detailed Justification

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| **Excess Facilities Disposition (EFD)** | **8,748** | **24,844** | **—** |

Funding for Excess Facilities Disposition supports removal of excess facilities at SC sites to reduce long-term costs and liabilities. EFD funding also supports cleanup of facilities for reuse when such reuse is economical and provides needed functionality. EFD funding is focused on disposal of facilities involving little, if any, contamination, such as the Bevatron D&D project at Lawrence Berkeley National Laboratory and small D&D projects at Argonne National Laboratory and Oak Ridge National Laboratory. Funding for projects other than the Bevatron was discontinued in FY 2009.

In FY 2009, $14,844,000 of EFD funding was provided to continue demolition of Building 51 and the Bevatron at LBNL. The FY 2009 work includes isolation of utility systems, abatement of hazardous materials, removal of shielding blocks and the Bevatron accelerator, and demolition of Building 51 structures. Additionally, funding planned to be provided under the Recovery Act in FY 2009 fully funds the project, resulting in no funding request for FY 2010. The project is scheduled to be complete in FY 2011 at a total cost of $50,000,000. The project's Performance Baseline was established in FY 2008.

In accordance with Congressional direction, $10,000,000 of FY 2009 EFD funding will be provided for cleanup efforts at Argonne National Laboratory.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| **Oak Ridge Landlord** | **5,033** | **5,079** | **5,214** |

This funding supports landlord responsibilities, including infrastructure for the 24,000 acres of the Oak Ridge Reservation outside of the Y-12 plant, ORNL and the East Tennessee Technology Park, and DOE facilities in the town of Oak Ridge. Supported activities include maintenance of roads, grounds and other infrastructure, support and improvement of environmental protection, safety and health, payment of PILT to Oak Ridge communities, and other needs related to landlord responsibilities. These activities maintain continuity of operations at the Oak Ridge Reservation and the DOE facilities in Oak Ridge, and minimize interruptions due to infrastructure or other systems failures.

| | | | |
|---|---|---|---|
| **Payments in Lieu of Taxes (PILT)** | **1,506** | **1,385** | **1,385** |

Provides PILT to support assistance requirements for communities around Argonne National Laboratory and Brookhaven National Laboratory. PILT payments are negotiated between Department and local governments based on land values and tax rates.

| | | | |
|---|---|---|---|
| **Total, Infrastructure Support** | **15,287** | **31,308** | **6,599** |

## Explanation of Funding Changes

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| **Infrastructure Support** | |
| **Excess Facilities Disposition (EFD)** | |
| Decrease due to final funding of the Bevatron project in FY 2009 and one-time Congressional Direction of $10,000,000 for cleanup efforts at Argonne National Laboratory. | -24,844 |
| **Oak Ridge Landlord** | |
| Increase to support reservation road repairs. | +135 |
| **Total Funding Change, Infrastructure Support** | **-24,709** |

## Construction

### Funding Schedule by Activity

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Construction | | | |
| Research Support Building and Infrastructure Modernization (SLAC) | — | — | 8,900 |
| Energy Sciences Building (ANL) | — | — | 10,000 |
| Renovate Science Laboratories, Phase II (BNL) | — | — | 7,000 |
| Seismic Life-Safety, Modernization, and Replacement of General Purpose Buildings, Phase II (LBNL) | — | 12,495 | 34,027 |
| Interdisciplinary Science Building, Phase I (BNL) | — | 8,240 | 39,387 |
| Technology and Engineering Development Facility (TJNAF) | — | 3,700 | 27,687 |
| Modernization of Laboratory Facilities (ORNL) | 9,329 | 25,103 | — |
| Physical Sciences Facility (PNNL) | 24,773 | 52,775 | — |
| Science Laboratories Infrastructure Project (Various) | 17,472 | 11,759 | — |
| Total, Construction | 51,574 | 114,072 | 127,001 |

### Description

The SLI Construction subprogram funds line item construction projects to maintain and enhance the general purpose infrastructure at SC laboratories. Infrastructure Modernization Initiative investments are included here and are focused on ensuring mission readiness at each SC laboratory. Projects are selected using a collaborative approach involving SC Site Office Managers, laboratory Chief Operating Officers, and the SC Deputy Directors for Field Operations and Programs. Projects are evaluated and prioritized based upon mission relevance, amount of deferred maintenance reduction, amount of excess infrastructure eliminated, return on investment (e.g., reduction in operations and maintenance costs), and the level of institutional commitment to the project. The projects identified in this budget reflect this process.

### Selected FY 2008 Accomplishments

- Significant progress was made on construction of the Physical Sciences Facility (PSF) at Pacific Northwest National Laboratory. This project is necessary to ensure continued research capabilities at this laboratory, as existing space is cleaned up and demolished by the Office of Environmental Management. In FY 2008, earthwork and placement of foundations and structural steel on all of the new facilities continued. The balance of facility construction activities as well as needed modifications to Building 325 was initiated following approval of Critical Decision (CD)-3B. This project is on track to meet its cost and schedule milestones.

- The Infrastructure Modernization Initiative also made significant progress in FY 2008. Four projects have successfully achieved approval of CD-1, Approve Alternative Selection and Cost Range. The three new projects included in the FY 2010 request for start of Project Engineering and Design have received Approval of Mission Need (CD-0) and are now beginning conceptual design activities.

With these accomplishments, these projects are well on their way to provide critically-needed infrastructure improvements at SC laboratories to ensure continued mission readiness.

## Detailed Justification

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| **Research Support Building & Infrastructure Modernization at SLAC (10-SC-70)** | **—** | **—** | **8,900** |

SLAC National Accelerator Laboratory has evolved from a single program to a multi-program laboratory. This transition, combined with the condition and age of SLAC facilities drives the need to consolidate core research groups and modernize key support buildings. The Research Support Building and Infrastructure Modernization project will replace substandard modular buildings and trailers that are well beyond their intended useful life with a new Research Support Building and will also modernize three existing buildings onsite. This is a new project and FY 2010 funds will be used for Project Engineering and Design.

| | | | |
|---|---|---|---|
| **Energy Sciences Building at ANL (10-SC-71)** | **—** | **—** | **10,000** |

Argonne National Laboratory research capabilities are currently hampered by antiquated, scientifically inadequate, and inefficient research space. This project will provide environmentally stable, specialized, and flexible space by constructing the new Energy Sciences Building to replace some of the oldest and least effective research space for energy-related sciences. This is a new project and FY 2010 funds will be used for Project Engineering and Design.

| | | | |
|---|---|---|---|
| **Renovate Science Lab, Phase II, at BNL (10-SC-72)** | **—** | **—** | **7,000** |

A large number of scientists and researchers at Brookhaven National Laboratory are conducting science in laboratories built over forty years ago. Two such buildings are Building 510 (Physics) and Building 555 (Chemistry). Although their basic building core and shell construction is sound, the lab and office spaces and their utilities and environmental support systems are obsolete. This project will modernize unsuitable laboratory space in these two buildings, allowing them to continue supporting research in Basic Energy Sciences and Nuclear and High Energy Physics. This is a new project and FY 2010 funds will be used for Project Engineering and Design.

| | | | |
|---|---|---|---|
| **Seismic Life-Safety, Modernization, and Replacement of General Purpose Buildings, Phase II, at LBNL (09-SC-72)** | **—** | **12,495** | **34,027** |

Lawrence Berkeley National Laboratory is located near the Hayward Fault. Recent building evaluations identified more than 30 buildings that would not survive a major earthquake without significant damage to the structure and appreciable life safety hazard to their occupants. This project will remedy high-seismic life-safety risks by replacing seismically-poor buildings and trailers with a new general-purpose laboratory/office building supporting Life Sciences. This project will also seismically upgrade the site-wide Hazardous Waste Handling Facility and modernize an existing Life Sciences building (Building 74). Early procurement for building renovations and initial construction activities are expected to take place in FY 2009. FY 2010 construction funding will be used to continue construction activities, including project management and all associated support functions.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| | (dollars in thousands) | | |
| **Interdisciplinary Science Building, Phase I, at BNL (09-SC-73)** | **—** | **8,240** | **39,387** |

This project will provide high accuracy laboratories (e.g., equipped with precise temperature, humidity, and vibration controls), offices, and support space for energy-related research and development in a new interdisciplinary facility. It is part of a broader modernization plan for the laboratory that includes construction of new facilities where capabilities cannot be incorporated into existing buildings or where extensive life-extension work is not cost efficient, and renovation of existing building and utilities where the infrastructure can be made conducive to meet mission needs. This project also includes demolition of offsetting space. FY 2010 funds will be used to continue construction activities.

| | | | |
|---|---|---|---|
| **Technology and Engineering Development Facility at TJNAF (09-SC-74)** | **—** | **3,700** | **27,687** |

The Technology and Engineering Development Facility project will ensure TJNAF facilities can reliably support production of advanced cryomodules with the quality required for ongoing and future projects and sustain the current high demand for mounting numerous unique large-scale particle detectors. It includes construction of new industrial assembly, laboratory, and office space to eliminate overcrowding and improve workflow and productivity by co-locating the engineering and technical functions currently spread across the laboratory. This project will also renovate existing space in the Test Lab Building, to provide efficient workflow, a safe and sustainable work environment, and functional efficiencies. Demolition of inadequate and obsolete work space is also included. FY 2010 funds will be used to start construction work on the new buildings, including project management and associated support activities.

| | | | |
|---|---|---|---|
| **Modernization of Laboratory Facilities at ORNL (08-SC-71)** | **9,329** | **25,103** | **—** |

Science operations of research groups housed in the ORNL 4500 Complex are affected by the functionality of the old, deteriorating building facilities. This project will construct a new chemical and materials science laboratory building to support research activities currently housed in the 4500 Complex. The project will provide modern, 21st-century research laboratories, with associated space for offices, small-group conference rooms, and support functions. The estimate for design activities (PED) has been revised downward. As a result, $2,800,000 of FY 2008 PED funds will be used for construction activities. FY 2009 funds provided final funding for this project and will be used to complete construction of the building, including project management and all associated support functions.

| | | | |
|---|---|---|---|
| **Physical Sciences Facility at PNNL (07-SC-05)** | **24,773** | **52,775** | **—** |

This project is for the construction of new laboratory and office space on the PNNL site north of Horn Rapids Road and complete life extension upgrades to the 325 Building to accommodate a portion of the existing research capabilities being displaced as a result of the closure and cleanup of facilities in the Hanford 300 Area. The FY 2009 appropriation fully funded the DOE portion of this project's cost and will be used to continue project construction activities as well as facility start-up and readiness activities.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| **Science Laboratories Infrastructure Project (MEL-001)** | **17,472** | **11,759** | **—** |
| ▪ **OSTI Facility Improvements (MEL-001-052)** | **—** | **2,500** | **—** |
| The subproject will provide critical roof replacement and upgrade of the fire safety protection system at the DOE-owned OSTI facility housing DOE's historic and current paper and electronic collection of energy-related R&D results. | | | |
| ▪ **Renovate Science Laboratory, Phase I, at BNL (MEL-001-050)** | **8,200** | **6,642** | **—** |
| This subproject will upgrade and rehabilitate existing obsolete and unsuitable laboratory facilities in Building 480 (Material Science Building) and Building 815 (Multi-Program Laboratory/Office building) into modern, efficient facilities compatible with world-class scientific research. | | | |
| ▪ **Seismic Safety Upgrade of Buildings, Phase I, at LBNL (MEL-001-047)** | **9,272** | **2,617** | **—** |
| This subproject will address the seismic vulnerability of laboratory buildings where high life-safety risks have been identified in Building 50 (Main Office Building) and Building 74 (Life Sciences). | | | |
| **Total, Construction** | **51,574** | **114,072** | **127,001** |

## Explanation of Funding Changes

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| **Research Support Building and Infrastructure Modernization at SLAC (10-SC-70)** | |
| Increase for initial Project Engineering and Design (PED). | +8,900 |
| **Energy Sciences Building at ANL (10-SC-71)** | |
| Increase for initial Project Engineering and Design (PED). | +10,000 |
| **Renovate Science Lab, Phase II, at BNL (10-SC-72)** | |
| Increase for initial Project Engineering and Design (PED). | +7,000 |
| **Seismic Life-Safety, Modernization, and Replacement of General Purpose Buildings, Phase II, at LBNL (09-SC-72)** | |
| Increased project funding per the preliminary Project Execution Plan. | +21,532 |
| **Interdisciplinary Science Building, Phase I, at BNL (09-SC-73)** | |
| Increased project funding per the preliminary Project Execution Plan. | +31,147 |
| **Technology and Engineering Development Facility at TJNAF (09-SC-74)** | |
| Increased project funding per the preliminary Project Execution Plan. | +23,987 |

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| **Modernization of Laboratory Facilities at ORNL (08-SC-71)** | |
| Funding was provided in FY 2009 to complete the project profile. | -25,103 |
| **Physical Sciences Facility at PNNL (07-SC-05)** | |
| Funding was provided in FY 2009 to complete the project profile. | -52,775 |
| **MEL-001, Science Laboratories Infrastructure Project** | |
| ▪ **OSTI Facility Improvements (MEL-001-052)** | |
| The FY 2009 appropriation provided full funding for these improvements. | -2,500 |
| ▪ **Renovate Science Laboratory, Phase I, at BNL (MEL-001-050)** | |
| Final funding provided in FY 2009 to revitalize and modernize laboratories in two buildings at Brookhaven National Laboratory (BNL). | -6,642 |
| ▪ **Seismic Safety Upgrade of Buildings, Phase I, at LBNL (MEL-001-047)** | |
| Final funding provided in FY 2009 for the first phase of seismic and structural safety upgrades at Lawrence Berkeley National Laboratory (LBNL). | -2,617 |
| **Total, Construction** | **+12,929** |

## Supporting Information

### Operating Expenses, Capital Equipment and Construction Summary

(dollars in thousands)

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| Operating Expenses | 15,187 | 31,208 | 6,499 |
| General Plant Projects | 100 | 100 | 100 |
| Construction | 51,574 | 114,072 | 127,001 |
| Total, Science Laboratories Infrastructure | 66,861 | 145,380 | 133,600 |

### Construction Projects

(dollars in thousands)

| | Prior Years | FY 2008 | FY 2009 | FY 2009 Additional Approp.[a] | FY 2010 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| 10-SC-70 Research Support and Infrastructure Modernization, SLAC | | | | | | | |
| TEC | — | — | — | — | 8,900 | TBD | 80,000-96,000 |
| OPC[b] | — | — | 500 | — | 900 | — | 1,400 |
| TPC | — | — | 500 | — | 9,800 | TBD | TBD |
| 10-SC-71 Energy Sciences Building, ANL | | | | | | | |
| TEC | — | — | — | — | 10,000 | TBD | 84,500-95,000 |
| OPC[b] | — | — | 1,000 | — | — | — | 1,000 |
| TPC | — | — | 1,000 | — | 10,000 | TBD | TBD |
| 10-SC-72 Renovate Science Labs, Phase II, BNL | | | | | | | |
| TEC | — | — | — | — | 7,000 | TBD | 45,000-50,000 |
| OPC[b] | — | — | 800 | — | — | — | 800 |
| TPC | — | — | 800 | — | 7,000 | TBD | TBD |
| 09-SC-72 Seismic Life-Safety, Mod, and Replacement of General Purpose Bldgs., Phase II, LBNL | | | | | | | |
| TEC | — | — | 12,495 | 15,000 | 34,027 | TBD | 91,900-94,600 |
| OPC[b] | — | 2,250 | 50 | — | — | — | 3,000 |
| TPC | — | 2,250 | 12,545 | 15,000 | 34,027 | TBD | TBD |
| 09-SC-73 Interdisciplinary Science Building, Phase I, BNL | | | | | | | |

[a] The Additional Appropriation column reflects the planned allocation of funding from the American Recovery and Reinvestment Act of 2009, P.L. 111–5. See the Department of Energy Recovery website at http://www.energy.gov/recovery for up-to-date information regarding Recovery Act funding.
[b] Other Project Costs shown are funded through laboratory overhead.

(dollars in thousands)

| | Prior Years | FY 2008 | FY 2009 | FY 2009 Additional Approp.[a] | FY 2010 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| TEC | — | — | 8,240 | 18,673 | 39,387 | TBD | 61,300-66,300 |
| OPC[a] | — | 500 | — | — | — | — | 500 |
| TPC | — | 500 | 8,240 | 18,673 | 39,387 | TBD | TBD |
| 09-SC-74 Technology and Engineering Development Facility, TJNAF | | | | | | | |
| TEC | — | — | 3,700 | — | 27,687 | TBD | 66,000-72,200 |
| OPC[a] | — | 1,000 | — | — | — | — | 1,000 |
| TPC | — | 1,000 | — | — | 27,687 | TBD | TBD |
| 08-SC-71 Modernization of Laboratory Facilities, ORNL | | | | | | | |
| TEC | — | 9,329 | 25,103 | 60,568 | — | — | 95,000 |
| OPC[a] | 700 | 400 | 100 | — | — | 100 | 1,300 |
| TPC | 700 | 9,729 | 25,203 | 60,568 | — | 100 | 96,300 |
| 07-SC-05 Physical Sciences Facility, PNNL | | | | | | | |
| TEC/TPC | 20,896 | 24,773 | 52,775 | — | — | — | 98,444 |
| MEL-001, Science Laboratories Infrastructure Project | | | | | | | |
| TEC/TPC | N/A | 17,472 | 11,759 | — | — | — | N/A |
| Total, Construction | | | | | | | |
| TEC | | 51,574 | 114,072 | 94,241 | 127,001 | | |
| OPC[a] | | 4,150 | 2,450 | — | 100 | | |
| TPC | | 55,724 | 116,522 | 94,241 | 127,101 | | |

## Indirect Costs and Other Items of Interest

### Institutional General Plant Projects (IGPP)

Institutional General Plant Projects are miscellaneous construction projects that have a total cost less than $10,000,000 and are of a general nature (cannot be allocated to a specific program). IGPPs support multi-programmatic and/or inter-disciplinary programs and are funded through site overhead. Examples of acceptable IGPPs include site-wide maintenance facilities and utilities, such as roads and grounds outside the plant fences or a telephone switch that serves the entire facility.

[a] Other Project Costs shown are funded through laboratory overhead.

The following displays IGPP funding by site:

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Argonne National Laboratory | 385 | 6,000 | 7,000 |
| Brookhaven National Laboratory | 439 | 6,820 | 7,059 |
| Lawrence Berkeley National Laboratory | 2,452 | 4,100 | 4,100 |
| Oak Ridge National Laboratory | 10,327 | 14,000 | 14,000 |
| Pacific Northwest National Laboratory | 623 | 1,500 | 1,500 |
| Stanford Linear Accelerator | — | 3,000 | 1,200 |
| Total, IGPP | 14,226 | 35,420 | 34,859 |

### Facilities Maintenance and Repair

The Department's facilities maintenance and repair activities are tied to its programmatic missions, goals, and objectives. Facilities Maintenance and Repair activities funded at SC laboratories are displayed in the following tables.

### Indirect-Funded Maintenance and Repair

Facilities maintenance and repair activities funded indirectly through overhead charges at SC laboratories are displayed below. Since this funding is allocated to all work done at each laboratory, these activities are paid for using funds from SC and other DOE organizations, as well other Federal agencies and other entities doing work at SC laboratories. Maintenance reported to SC for non-SC laboratories is also shown.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Ames Laboratory | 1,045 | 1,031 | 1,066 |
| Argonne National Laboratory | 33,948 | 31,402 | 31,675 |
| Brookhaven National Laboratory | 24,918 | 31,736 | 32,797 |
| Fermi National Accelerator Laboratory | 8,752 | 9,668 | 9,891 |
| Lawrence Berkeley National Laboratory | 14,028 | 16,099 | 19,285 |
| Lawrence Livermore National Laboratory | 2,887 | 2,563 | 2,614 |
| Los Alamos National Laboratory | 100 | 111 | 113 |
| Oak Ridge Institute for Science and Education | 562 | 301 | 308 |
| Oak Ridge National Laboratory | 39,242 | 39,487 | 40,396 |
| Oak Ridge National Laboratory facilities at Y-12 | 1,821 | 838 | 857 |
| Office of Scientific and Technical Information | 330 | 338 | 346 |
| Pacific Northwest National Laboratory | 2,790 | 1,215 | 1,919 |
| Princeton Plasma Physics Laboratory | 5,502 | 5,636 | 6,052 |
| Sandia National Laboratories | 2,045 | 2,402 | 2,450 |

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| | (dollars in thousands) | | |
| Stanford Linear Accelerator Center | 6,716 | 4,881 | 4,904 |
| Thomas Jefferson National Accelerator Facility | 3,039 | 3,540 | 3,700 |
| Total, Indirect-Funded Maintenance and Repair | 147,725 | 151,248 | 158,373 |

### Direct-Funded Maintenance and Repair

Generally, facilities maintenance and repair expenses are funded through an indirect overhead charge. In some cases, however, a laboratory may charge maintenance directly to a specific program. For example when maintenance is performed in a building used only by a single program. These direct-funded charges are nonetheless in the nature of indirect charges, and therefore are not directly budgeted. The maintenance work for the Oak Ridge Office is direct funded and direct budgeted by the Science Laboratories Infrastructure program. A portion of the direct-funded maintenance and repair expenses reflects charges to non-SC programs performing work at SC laboratories.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| | (dollars in thousands) | | |
| Brookhaven National Laboratory | 5,161 | 1,500 | 1,552 |
| Fermilab National Accelerator Facility | 3,801 | 3,854 | 3,943 |
| Notre Dame Radiation Laboratory | 124 | 169 | 177 |
| Oak Ridge National Laboratory | 21,425 | 16,151 | 16,066 |
| Oak Ridge Office | 550 | 2,642 | 2,790 |
| Stanford Linear Accelerator Center | 5,261 | 7,239 | 7,357 |
| Thomas Jefferson National Accelerator Facility | 88 | 57 | 59 |
| Total, Direct-Funded Maintenance and Repair | 36,410 | 31,612 | 31,944 |

### Deferred Maintenance Backlog Reduction

SC is working to reduce the backlog of deferred maintenance at its laboratories: Argonne, Brookhaven, Lawrence Berkley, Oak Ridge, and Pacific Northwest national laboratories; the Ames Laboratory, Fermilab National Accelerator Facility, Princeton Plasma Physics Laboratory, Stanford Linear Accelerator Center, and Thomas Jefferson National Accelerator Facility; and other SC facilities in Oak Ridge and Notre Dame laboratories. The total deferred maintenance backlog at the end of FY 2008 is estimated to be $462,000,000.

The primary strategy for reducing deferred maintenance is SC's proposed Infrastructure Modernization Initiative, which will modernize the general purpose infrastructure at SC laboratories. The initiative focuses on increased funding for line item construction projects which will result in significant additional reductions to the deferred maintenance backlog, but are not included within the indirect funding in the following table. In addition, SC laboratories are funding deferred maintenance reduction efforts via overhead, IGPP, GPP, and line items.

The table below shows the expected funding from laboratory overhead for deferred maintenance reduction.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008[a] | FY 2009[b] | FY 2010[b] |
| Argonne National Laboratory | 2,042 | 4,581 | 3,800 |
| Brookhaven National Laboratory | 5,445 | 8,147 | 10,300 |
| Fermi National Accelerator Laboratory | 5,254 | 2,810 | 3,693 |
| Lawrence Berkeley National Laboratory | 4,349 | 2,500 | 2,000 |
| Oak Ridge National Laboratory | 8,728 | 6,500 | 6,500 |
| Princeton Physics Plasma Laboratory | 177 | 258 | 340 |
| Stanford Linear Accelerator Center | 686 | 850 | 953 |
| Thomas Jefferson National Accelerator Facility | 658 | 500 | 800 |
| Total, Deferred Maintenance Backlog Reduction | 27,339 | 26,146 | 28,386 |

[a] Includes deferred maintenance reduction funding from overhead and IGPP
[b] Includes deferred maintenance reduction funding from overhead

## 10-SC-70, Research Support Building and Infrastructure Modernization, SLAC National Accelerator Laboratory, Menlo Park, California Project Data Sheet is for PED

### 1. Significant Changes

The most recent DOE O413.3A Critical Decision (CD) is CD-0 (Approve Mission Need) that was approved on October 10, 2008 with a preliminary Total Estimated Cost (TEC) range of $80,000,000–$96,000,000.

A Federal Project Director with certification level II has been assigned to this project.

This Project Data Sheet is new for PED.

### 2. Design, Construction, and D&D Schedule

| | CD-0 | CD-1 | (Design/PED Complete) | CD-2 | CD-3 | CD-4) | D&D Start | D&D Complete |
|---|---|---|---|---|---|---|---|---|
| FY 2010 | 10/10/2008 | 1Q FY2010 | 2Q FY2011 | TBD | TBD | TBD | TBD | TBD |

CD-0 – Approve Mission Need
CD-1 – Approve Alternative Selection and Cost Range
CD-2 – Approve Performance Baseline
CD-3 – Approve Start of Construction
CD-4 – Approve Start of Operations or Project Closeout
D&D Start – Start of Demolition & Decontamination (D&D) work
D&D Complete –Completion of D&D work

### 3. Baseline and Validation Status

| | TEC, PED | TEC, Construction | TEC, Total | OPC Except D&D | OPC, D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2010 | $8,900 | TBD | TBD[a] | $1,400[b] | TBD | TBD | TBD |

### 4. Project Description, Justification, and Scope

SLAC National Accelerator Laboratory is an Office of Science (SC) laboratory that supports a large national and international community of scientific users performing cutting edge research in support of the Department of Energy mission. Success of that mission is directly coupled to the general purpose infrastructure necessary to conduct this research. At SLAC, accomplishment of that mission is currently at-risk given substandard buildings that do not provide the appropriate environment to conduct world class science or mission support functions.

SLAC has moved from a single program to a multi-program laboratory; this transition, combined with the condition and age of SLAC facilities, drives the need to consolidate core research functions and

[a] Costs are to be determined. The preliminary TEC range is $80,000,000 to $96,000,000.
[b] Other Project Costs of $1,400,000 are funded through laboratory overhead.

modernize key support buildings. The most pressing infrastructure gaps are the lack of appropriate space to house and co-locate accelerator scientists and key mission support staff who are currently spread across the laboratory in outdated and inefficient facilities.

To correct these deficiencies, a new building is proposed to house the laboratory's accelerator scientists. This new building will replace numerous 40-year-old trailers that currently support the laboratory's accelerator scientists. This will enable integration of the accelerator science and technology community across programmatic boundaries, allowing these scientists to better support the science missions at the laboratory. In addition, renovation of three buildings is proposed (i.e., 003, 024, and 041). These buildings house key mission support functions and were part of the original construction of the laboratory in the mid-1960s. Although the basic core and shell construction are sound, their interior spaces and utility system are obsolete. Overall, the proposed project will upgrade working conditions for over 20% of the laboratory staff in a way that supports the laboratory vision of a unified culture with a strong sense of community between all scientific and support functions across the laboratory.

The project is being conducted in accordance with the project management requirements in DOE O 413.3A and DOE M 413.3-1, Program and Project Management for the Acquisition of Capital Assets, and all appropriate project management requirements have been met.

## 5. Financial Schedule

(dollars in thousands)

| | Appropriations | Obligations | Costs |
|---|---|---|---|
| Total Estimated Cost (TEC) | | | |
| PED | | | |
| FY 2010 | 8,900 | 8,900 | 5,900 |
| FY 2011 | — | — | 3,000 |
| Total, TEC | 8,900 | 8,900 | 8,900 |
| Other Project Cost (OPC)[a] | | | |
| FY 2009 | 500 | 500 | 500 |
| FY 2010 | 900 | 900 | 900 |
| Total, OPC | 1,400 | 1,400 | 1,400 |
| Total Project Cost (TPC) | | | |
| FY 2009 | 500 | 500 | 500 |
| FY 2010 | 9,800 | 9,800 | 6,800 |
| Outyears | — | — | 3,000 |
| Total, TPC | 10,300[b] | 10,300[b] | 10,300[b] |

[a] Other Project Costs of $1,400,000 are funded through laboratory overhead.
[b] This Project has not yet received approval of CD-2; therefore estimates displayed only include funding for PED and associated other project costs. The preliminary TEC range is $80,000,000 to $96,000,000.

## 6. Details of Project Cost Estimate

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| Total Estimated Cost (TEC) | | | |
| Design (PED) | | | |
| Design | 6,675 | N/A | N/A |
| Contingency | 2,225 | N/A | N/A |
| Total, PED | 8,900 | N/A | N/A |
| Total, TEC | 8,900 | N/A | N/A |
| Contingency, TEC | 2,225 | N/A | N/A |
| Other Project Cost (OPC) | | | |
| OPC[a] | | | |
| Other OPC | 900 | N/A | N/A |
| Start-Up | 300 | N/A | N/A |
| Contingency | 200 | N/A | N/A |
| Total, OPC | 1,400 | N/A | N/A |
| Total, TPC[b] | 10,300 | N/A | N/A |
| Total, Contingency | 2,425 | N/A | N/A |

## 7. Schedule of Project Costs

For schedule of project costs, see Section 5, "Financial Schedule."

## 8. Related Operations and Maintenance Funding Requirements

Not applicable for PED.

## 9. Required D&D Information

Not applicable for PED.

## 10. Acquisition Approach

Not applicable for PED.

[a] Other Project Costs of $1,400,000 are funded through laboratory overhead.
[b] This Project has not yet received approval of CD-2; therefore estimates displayed only include funding for PED and associated other project costs. The preliminary TEC range is $80,000,000 to $96,000,000.

## 10-SC-71, Energy Sciences Building, Argonne National Laboratory (ANL), Argonne, IL
## Project Data Sheet is for PED

### 1. Significant Changes

The most recent DOE O 413.3A approved Critical Decision (CD) is CD-0, Approve Mission Need, which was approved on October 10, 2008, with a preliminary Total Estimated Cost (TEC) range of $84,500,000 to $95,000,000.

A Federal Project Director has been assigned to this project. Project is pursuing to fulfill the certification requirements.

This Project Data Sheet is new for PED.

### 2. Design, Construction, and D&D Schedule

(fiscal quarter or date)

| | CD-0 | CD-1 | (Design / PED Complete) | CD-2 | CD-3 | CD-4 | D&D Start | D&D Complete |
|---|---|---|---|---|---|---|---|---|
| FY 2010 | 10/10/2008 | 4Q FY 2009 | 2Q FY 2011 | TBD | TBD | TBD | TBD | TBD |

CD-0 – Approve Mission Need
CD-1 – Approve Alternative Selection and Cost Range
CD-2 – Approve Performance Baseline
CD-3 – Approve Start of Construction
CD-4 – Approve Start of Operations or Project Closeout
D&D Start – Start of Demolition & Decontamination (D&D) work
D&D Complete –Completion of D&D work

### 3. Baseline and Validation Status

(dollars in thousands)

| | TEC, PED | TEC, Construction | TEC, Total | OPC Except D&D | OPC, D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2010 | 10,000 | TBD | TBD[a] | 1,000[b] | TBD | TBD | TBD |

### 4. Project Description, Justification, and Scope

This project will provide new energy efficient and environmentally sustainable laboratory space at Argonne National Laboratory (ANL) that will provide modern, 21st-century, high-accuracy laboratories for energy-related research and development (R&D) and associated space for support functions. The design will utilize modern, efficient laboratory planning benchmarks as the basis for determining the size and configuration of space types. The design of the space will also emphasize more open, collaborative environments and flexibility to respond to future mission changes. In addition to the research laboratories, the building will include office space for researchers, small group conference rooms, equipment areas, restrooms, circulation space, and supporting infrastructure.

The objective of the Energy Sciences Building (ESB) project is to provide high-accuracy, flexible, and sustainable laboratory and office space to support scientific theory/simulation, materials discovery,

[a] Preliminary Total Estimated Cost (TEC) range is $84,500,000 to $95,000,000.
[b] Other Project Costs of $1,000,000 are funded through laboratory overhead.

characterization, and application of new energy-related materials and processes. Efficient, high-accuracy heating, ventilation, and air conditioning (HVAC) systems will be installed to support cutting edge research and the operation of sensitive instrumentation. Comparable space is not available at ANL. The scope of the project includes design, construction, and start-up of the new facility and extension of existing site utilities to the new building.

Key areas of energy research to be housed in the ESB include: discovery synthesis, biomimetics and solar energy, catalysis, fuel cell research, and electrical energy storage. These five research areas currently lack modern scientific space needed for seamless multi-disciplinary collaborative research, the hallmark of 21st century science and engineering.

ANL research buildings dedicated to the SC energy research mission are all more than 40 years old, some as much as 55 years old. They require constant repair and frequently compromise or halt scientific research and are unable to meet modern standards for high resolution apparatus requiring vibration, electromagnetic, and thermal stability. Electrical power in these facilities is unstable and insufficient for modern synthesis and measurement instruments to operate at rated performance levels. Temperature and humidity controls were designed for human comfort only and not for state-of-the-art experimental performance, resulting in erratic temperature and humidity fluctuations over a few hours requiring frequent recalibration of apparatus to achieve sufficient measuring accuracy. Several key laboratories can operate only at night because of excessive vibration, temperature, and power fluctuations in the daytime, significantly impeding productivity. In addition to the functional inadequacies described above, safety and building code noncompliances further compromise ANL's ability to support SC and the Department's long-term energy goals. Antiquated and/or outdated electrical, fire protection, and ventilation systems have resulted in numerous National Electric (NEC) and National Fire Protection Association (NFPA) code deficiencies. The age of these facilities and systems as well as the inability to obtain replacement parts has limited ANL's ability to correct these deficiencies via replacement and/or capital improvements.

The project is being conducted in accordance with the project management requirements in DOE O 413.3A, Program and Project Management for the Acquisition of Capital Assets, and all appropriate project management requirements have been met.

## 5. Financial Schedule

(dollars in thousands)

| | Appropriations | Obligations | Costs |
|---|---|---|---|
| Total Estimated Cost (TEC) | | | |
| PED | | | |
| FY 2010 | 10,000 | 10,000 | 7,000 |
| FY 2011 | — | — | 3,000 |
| Total, TEC | 10,000 | 10,000 | 10,000 |
| | | | |
| Other Project Cost (OPC) [a] | | | |
| OPC except D&D | | | |
| FY 2009 | 1,000 | 1,000 | 1,000 |

[a] Other Project Costs of $1,000,000 are funded through laboratory overhead.

| | (dollars in thousands) | | |
|---|---|---|---|
| | Appropriations | Obligations | Costs |
| Total Project Cost (TPC) | | | |
| FY 2009 | 1,000 | 1,000 | 1,000 |
| FY 2010 | 10,000 | 10,000 | 7,000 |
| FY 2011 | — | — | 3,000 |
| Total, TPC | 11,000[a] | 11,000[a] | 11,000[a] |

## 6. Details of Project Cost Estimate

| | (dollars in thousands) | | |
|---|---|---|---|
| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
| Total Estimated Cost (TEC) | | | |
| Design (PED) | | | |
| Design | 8,688 | N/A | N/A |
| Contingency | 1,312 | N/A | N/A |
| Total, TEC | 10,000 | N/A | N/A |
| | | | |
| Other Project Cost (OPC) | | | |
| OPC except D&D | | | |
| Conceptual Planning | 263 | N/A | N/A |
| Conceptual Design | 603 | N/A | N/A |
| Contingency | 134 | N/A | NA |
| Total, OPC | 1,000 | N/A | N/A |
| Contingency, OPC | 134 | N/A | N/A |
| | | | |
| Total, TPC | 11,000[a] | N/A | N/A |
| Total, Contingency | 1,446 | N/A | N/A |

## 7. Schedule of Project Costs

For schedule of project costs, see Section 5, "Financial Schedule."

## 8. Related Operations and Maintenance Funding Requirements

Not applicable for PED.

## 9. Required D&D Information

Not applicable for PED.

## 10. Acquisition Approach

Not applicable for PED.

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[a] This project has not yet received approval of CD-2; therefore, the TPC estimate displayed only includes project engineering and design and related other project costs. The preliminary total estimated cost range for this project is $84,500,000 to $95,000,000.

**10-SC-72, Renovate Science Labs, Phase II**
**Brookhaven National Laboratory (BNL), Upton, New York**
**Project Data Sheet is for PED**

## 1. Significant Changes

The most recent DOE O 413.3A approved Critical Decision (CD) is CD-0, Approve Mission Need, which was approved on October 10, 2008, with a preliminary Total Estimated Cost (TEC) range of $45,000,000 to $50,000,000.

A Federal Project Director with certification level II has been assigned to this project.

This Project Data Sheet is new for PED.

## 2. Design, Construction, and D&D Schedule

(fiscal quarter or date)

| | CD-0 | CD-1 | (Design/PED Complete) | CD-2 | CD-3 | CD-4 | D&D Start | D&D Complete |
|---|---|---|---|---|---|---|---|---|
| FY 2010 | 10/10/2008 | 4Q FY 2009 | 3Q FY 2011 | TBD | TBD | TBD | TBD | TBD |

CD-0 – Approve Mission Need
CD-1 – Approve Alternative Selection and Cost Range
CD-2 – Approve Performance Baseline
CD-3 – Approve Start of Construction
CD-4 – Approve Start of Operations or Project Closeout
D&D Start – Start of Demolition & Decontamination (D&D) work
D&D Complete –Completion of D&D work

## 3. Baseline and Validation Status

(dollars in thousands)

| | TEC, PED | TEC, Construction | TEC, Total | OPC Except D&D | OPC, D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2010 | 7,000 | TBD | TBD[a] | 800[b] | TBD | TBD | TBD |

## 4. Project Description, Justification, and Scope

A large number of scientists and researchers at BNL are conducting science in laboratories built over forty years ago. Although their basic building core and shell construction is sound, the lab and office spaces, and their utilities and environmental support systems, are totally obsolete.

The Renovate Science Labs, Phase II Project will upgrade and rehabilitate existing, obsolete, and unsuitable BNL laboratory facilities into modern, efficient laboratory spaces compatible with world-class scientific research. This project will revitalize and modernize laboratories and support space located in each of two buildings, Building 510 Physics and Building 555 Chemistry.

The laboratories in Building 510 for the Physics Department were constructed in 1962 and need renovation and modernization in order to keep pace with the highly complex and rapidly changing technologies required for work on advanced new detectors. This work involves sophisticated electronics,

[a] Preliminary Total Estimated Costs (TEC) range is $45,000,000 to $50,000,000.
[b] Other Project Costs of $800,000 are funded through laboratory overhead.

high precision mechanical assemblies, and extremely clean work areas for detectors such as silicon or gas filled devices. A task force conducted a condition assessment of the laboratories and developed a list of deficiencies, that included damaged floors and ceilings, roof and ceiling leaks, old and unused plumbing, including sinks and hoods in some laboratories, poor lighting levels, decrepit lab furniture, poor temperature control and ventilation, significant particulate discharge from HVAC systems, electromagnetic interference on electrical power in certain laboratories, and lack of fire sprinkler protection.

Likewise, Building 555 has a robust design for chemical sciences research, but was constructed in 1966 and now has a number of substantial limitations for current research needs. While building 555 has an effective design for wet chemistry, it needs to be renovated to address very serious infrastructure quality issues that have grown over the years. Its design can also accommodate the evolving need for laser and instrumentation space for many of the physical methods in use, but an upgrade of facilities for air, water and electrical is critical, and selective laboratory reconfiguration is needed to best meet advanced instrumentation needs.

The project is being conducted in accordance with the project management requirements in DOE O413.3A and all appropriate project management requirements have been met.

## 5. Financial Schedule

(dollars in thousands)

| | Appropriations | Obligations | Costs |
|---|---|---|---|
| Total Estimated Cost (TEC) | | | |
| PED | | | |
| FY 2010 | 7,000 | 7,000 | 2,800 |
| FY 2011 | — | — | 4,200 |
| Total, TEC | 7,000 | 7,000 | 7,000 |
| Other Project Cost (OPC)[a] | | | |
| OPC except D&D | | | |
| FY 2009 | 800 | 800 | 800 |
| Total Project Cost (TPC) | | | |
| FY 2009 | 800 | 800 | 800 |
| FY 2010 | 7,000 | 7,000 | 2,800 |
| FY 2011 | — | — | 4,200 |
| Total, TPC, PED | 7,800 | 7,800 | 7,800 |

[a] Other Project Costs of $800,000 are funded through laboratory overhead.

## 6. Details of Project Cost Estimate[a]

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| Total Estimated Cost (TEC) | | | |
| Design (PED) | | | |
| Design | 6,200 | N/A | N/A |
| Contingency | 800 | N/A | N/A |
| Total, TEC | 7,000 | N/A | N/A |
| | | | |
| Other Project Cost (OPC) | | | |
| OPC except D&D | | | |
| Conceptual Planning | 150 | N/A | N/A |
| Conceptual Design | 600 | N/A | N/A |
| Contingency | 50 | N/A | N/A |
| Total, OPC | 800 | N/A | N/A |
| Contingency, OPC | 50 | N/A | N/A |
| | | | |
| Total, TPC | 7,800 | N/A | N/A |
| Total, Contingency | 850 | N/A | N/A |

## 7. Schedule of Project Costs

For schedule of project costs, see Section 5, "Financial Schedule."

## 8. Related Operations and Maintenance Funding Requirements

Not applicable for PED.

## 9. Required D&D Information

Not applicable for PED.

## 10. Acquisition Approach

Not applicable for PED.

[a] This project has not yet received approval of CD-2; therefore the estimates displayed only include funding for PED and associated other project costs. The preliminary total estimated cost range for this project is $45,000,000 to $50,000,000.

**09-SC-72, Seismic Life-Safety, Modernization, and Replacement of General Purpose Buildings, Phase 2, Lawrence Berkeley National Laboratory (LBNL), Berkeley, California**
**Project Data Sheet is for PED/Construction**

## 1. Significant Changes

The most recent DOE O 413.3A approved Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range, which was approved on September 23, 2008 with a preliminary Total Estimated Cost (TEC) range of $91,900,000–$94,600,000.

A Federal Project Director with a certification level II has been assigned to this project.

This Project Data Sheet (PDS) is an update of the FY 2009 PDS.

## 2. Design, Construction, and D&D Schedule

(fiscal quarter or date)

| | CD-0 | CD-1 | (Design/PED Complete) | CD-2A | CD-2B/3A | CD-4 | D&D Start | D&D Complete |
|---|---|---|---|---|---|---|---|---|
| FY 2009 | 9/18/2007 | 2Q FY 2009 | 3Q FY 2010 | 2Q FY 2010 | TBD | TBD | TBD | TBD |
| FY 2010 | 9/18/2007 | 9/23/2008[a] | 4Q FY 2010 | 2Q FY 2010 | TBD | TBD | TBD | TBD |

CD-0 – Approve Mission Need
CD-1 – Approve Alternative Selection and Cost Range
CD-2A, Approve the Performance Baseline and Long-Lead Procurement for Building 74 Modernization
CD-2B/3A, Approve the Performance Baseline, and Approve Start of Construction for Building 74 Modernization.

## 3. Baseline and Validation Status

(dollars in thousands)

| | TEC, PED | TEC, Construction | TEC, Total | OPC Except D&D[b] | OPC, D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2009 | 8,680 | TBD | TBD | 2,300 | TBD | TBD | TBD |
| FY 2010 | 9,680 | TBD | TBD | 2,300 | TBD | TBD | TBD |

## 4. Project Description, Justification, and Scope

The objective of this project is to replace seismically unstable, high maintenance facilities at the Lawrence Berkeley National Laboratory (LBNL) with modern, seismically stable, state of the art laboratory space in support of the mission requirements of the Office of Science.

This project includes the modernization of Building 74, including upgrades to building systems and approximately 28,000 to 45,000 gross square feet (GSF) of laboratory/office space; construction of a 35,000 - 43,000 GSF General Purpose Laboratory (GPL); seismic upgrades and slope stabilization for Building 85, the site-wide Hazardous Waste Handling Facility; and demolition of offsetting space. The project includes all necessary design and construction activities and start-up of operations for both the new facility and Building 74.

[a] The Department of Energy was under a continuing resolution for more than 5 months in FY 2009. As a result, this project did not receive PED funds and was not able to begin preliminary design until April 2009.
[b] Other Project Costs of $2,300,000 are funded through laboratory overhead.

Lawrence Berkeley National Laboratory (LBNL) is an Office of Science multi-program national laboratory with a mission to perform leading multidisciplinary research in the fields of energy sciences, general sciences, and life sciences. The laboratory's research makes use of multidisciplinary collaboration and advanced engineering, computation, communications, fabrication, and other support facilities characteristic of a national laboratory. The laboratory's facilities are planned, constructed, and maintained to support the research programs and scientific goals, while maintaining compatibility with the university community and the surrounding physical setting. Research at LBNL is directly tied to the quality of its facilities and site improvements through a proactive building and utility maintenance program.

LBNL completed seismic evaluations of all permanently owned and occupied LBNL buildings in FY 2007. These evaluations have revealed that several buildings are seismically unsafe, and would not be able to survive a major earthquake without significant damage to the structure and appreciable life safety hazard to their occupants. The U.S. Geological Survey has estimated the probability of a major seismic event in the San Francisco Bay Area at 67% in the next 30 years. LBNL is located less than one kilometer from the Hayward Fault and will be subjected to severe shaking during a major seismic event on this fault.

This project will provide safe, modern, and energy efficient laboratories for multidisciplinary biology which directly benefit science at the interface of physical, life, and computational sciences. The research performed in these facilities will support and enhance work conducted at LBNL user facilities including the Advanced Light Source, the National Center for Electron Microscopy, and the Molecular Foundry. Additionally, a number of scientific areas of research will benefit from being co-located as a result of this project.

FY 2009 PED funding will be used for design of the project, including project management and all associated support functions. FY 2009 construction funding will support early procurement of mechanical and electrical systems for Building 74 including project management and all associated support functions. FY 2010 construction funding will be used for continued construction activities on this project, including project management and all associated support functions.

The project is being conducted in accordance with the project management requirements in

DOE O 413.3A, Program and Project Management for the Acquisition of Capital Assets, and all appropriate project management requirements have been met.

## 5. Financial Schedule

(dollars in thousands)

| | Appropriations | Obligations | Recovery Act Costs | Costs |
|---|---|---|---|---|
| Total Estimated Cost (TEC) | | | | |
| PED[a] | | | | |
| FY 2009 | 8,680 | 8,680 | — | 2,360 |
| FY 2009 Recovery Act | 1,000 | 1,000 | 1,000 | — |
| FY 2010 | — | — | — | 6,050 |
| Outyears | — | — | — | 270 |
| Total, PED | 9,680 | 9,680 | 1,000 | 8,680 |
| Construction | | | | |
| FY 2009 | 3,815 | 3,815 | — | 120 |
| FY 2009 Recovery Act | 14,000 | 14,000 | 560 | — |
| FY 2010 | 34,027 | 34,027 | 6,360 | 1,290 |
| Outyears | TBD | TBD | 7,080 | TBD |
| Total Construction | TBD | TBD | 14,000 | TBD |
| Total, TEC | TBD | TBD | 15,000 | TBD |
| Other Project Cost (OPC)[b] | | | | |
| OPC except D&D | | | | |
| FY 2008 | 2,250 | 2,250 | — | 2,250 |
| FY 2009 | 50 | 50 | — | 50 |
| Outyears | TBD | TBD | — | TBD |
| Total, OPC | TBD | TBD | — | TBD |

[a] All designs will be completed in less than 18 months.
[b] Other Project Costs of $2,300,000 are funded through laboratory overhead.

(dollars in thousands)

| | Appropriations | Obligations | Recovery Act Costs | Costs |
|---|---|---|---|---|
| Total Project Cost (TPC) | | | | |
| FY 2008 | 2,250 | 2,250 | — | 2,250 |
| FY 2009 | 12,545 | 12,545 | — | 2,530 |
| FY 2009 Recovery Act | 15,000 | 15,000 | 1,560 | — |
| FY 2010 | 34,027 | 34,027 | 6,360 | 7,340 |
| Outyears | TBD | TBD | 7,080 | TBD |
| Total, TPC[a] | TBD | TBD | 15,000 | TBD |

## 6. Details of Project Cost Estimate

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| Total Estimated Cost (TEC) | | | |
| Design (PED) | | | |
| Design | 8,027 | 8,234 | N/A |
| PED Contingency | 1,653 | 1,446 | N/A |
| Total, PED | 9,680 | 9,680 | N/A |
| Construction[a] | | | |
| Construction | 43,202 | 3,815 | N/A |
| Construction Contingency | 8,640 | — | N/A |
| Total Construction | 51,842 | 3,815 | N/A |
| Total TEC | 61,522 | 12,495 | N/A |
| Contingency, TEC | 10,293 | 1,446 | N/A |
| Other Project Cost (OPC) | | | |
| OPC except D&D | | | |
| Conceptual Planning and Design | 2,142 | 2,107 | N/A |
| Contingency | 158 | 193 | N/A |
| Total, OPC | 2,300 | 2,300 | N/A |
| Contingency, OPC | 158 | 193 | N/A |
| Total, TPC[a] | TBD | 16,395 | N/A |
| Total Contingency | TBD | 1,639 | N/A |

[a] This project has not yet received approval of CD-2; therefore, construction, TEC, and OPC estimates displayed only include PED, related other project costs, and initial construction costs. Construction funds will not be executed without appropriate Acquisition Executive approval. The preliminary total estimated cost range for this project is $91,900,000 to $94,600,000.

## 7. Schedule of Project Costs

For schedule of project costs, see Section 5, "Financial Schedule."

## 8. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy (fiscal quarter or date) | 2Q FY 2015 |
| Expected Useful Life (number of years) | 30 |
| Expected Future Start of D&D of this capital asset (fiscal quarter) | 2Q FY 2045 |

## (Related Funding requirements)

(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | Current Total Estimate | Previous Total Estimate | Current Total Estimate | Previous Total Estimate |
| Operations | 640 | N/A | 19,203 | N/A |
| Maintenance | 1,407 | N/A | 42,219 | N/A |
| Total, Operations & Maintenance | 2,047 | N/A | 61,422 | N/A |

## 9. Required D&D Information

| | Square Feet |
|---|---|
| Area of new construction | 35,000–43,000 |
| Area of existing facility(s) being replaced[a] | 1,560 |
| Area of additional D&D space to meet the "one-for-one" requirement[b] | 33,440–41,440 |

## 10. Acquisition Approach

A building program and design criteria will be developed by the LBNL Facilities Department incorporating detailed functional requirements. An architect-engineering firm with appropriate multidisciplinary design experience will be selected, based on qualifications, for design services. A lump-sum Construction Management /General Contracting (CM/GC) subcontract will be negotiated and awarded by the University of California. Independent reviews of the structural design and construction cost estimate will be arranged by LBNL.

[a] Building 74F (1,560SF) will be demolished to make way for the new General Purpose Laboratory.
[b] This project includes demolition of appropriate offsetting space to meet this requirement prior to Critical Decision-4.

**09-SC-73, Interdisciplinary Science Building, Phase I, Brookhaven National Laboratory (BNL), Upton, New York**
**Project Data Sheet is for PED/Construction**

## 1. Significant Changes

The most recent DOE O 413.3A approved Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range, which was approved on September 23, 2008, with a preliminary Total Estimated Cost (TEC) range of $61,300,000 to $66,300,000.

A Federal Project Director with certification level II has been assigned to this project.

This Project Data Sheet is a continuation of a PED PDS proceeding to construction. The significant change is that the estimated size range of the new facility has been revised downward due to volatile market conditions and uncertainties in escalation. The final scope will be established at CD-2. The TEC range remains unchanged.

## 2. Design, Construction, and D&D Schedule

(fiscal quarter or date)

| | CD-0 | CD-1 | (Design/PED Complete) | CD-2 | CD-3 | CD-4 | D&D Start | D&D Complete |
|---|---|---|---|---|---|---|---|---|
| FY 2009 | 09/18/2007 | 2Q FY 2009 | 3Q FY 2010 | 2Q FY 2010 | TBD | TBD | TBD | TBD |
| FY 2010 | 09/18/2007 | 09/23/2008[a] | 2Q FY 2010 | 2Q FY 2010 | TBD | TBD[b] | TBD | TBD |

CD-0 – Approve Mission Need
CD-1 – Approve Alternative Selection and Cost Range
CD-2 – Approve Performance Baseline
CD-3 – Approve Start of Construction
CD-4 – Approve Start of Operations or Project Closeout
D&D Start – Start of Demolition & Decontamination (D&D) work
D&D Complete – Completion of D&D work

## 3. Baseline and Validation Status

(dollars in thousands)

| | TEC, PED | TEC, Construction | TEC, Total[c] | OPC Except D&D[d] | OPC, D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2009 | 8,240 | TBD | TBD | 500 | TBD | TBD | TBD |
| FY 2010 | 8,240 | TBD | TBD | 500 | TBD | TBD | TBD |

[a] The Department of Energy was under a continuing resolution for more than 5 months in FY 2009. As a result, this project did not receive PED funds and was not able to begin preliminary design until April 2009.
[b] The preliminary CD-4 range is 3Q FY 2012 to 4Q FY 2013.
[c] Preliminary Total Estimated Cost (TEC) range is $61,300,000 to $66,300,000. No construction funds, other than for early site preparation activities, will be used until the project performance baseline has been validated and CD-3 approved.
[d] Other Project Costs of $500,000 are funded through laboratory overhead.

## 4. Project Description, Justification, and Scope

A large number of scientists and researchers at BNL are conducting science in left-over Army barracks that were modified to serve as laboratories and offices. These buildings are over 50 years old and have numerous functional and maintenance problems including wood rot, poor heat and ventilation, roof leaks, inadequate electrical services, and cramped space. Major investment would be needed to continue usage of these buildings that would otherwise be better invested in a new modern facility. In addition, the decentralized distribution of staff in old, ineffective buildings is demoralizing and decreases effective exchange of ideas between staff members.

The proposed Interdisciplinary Science Building, Phase I Project will construct 65,000 to 90,000 square feet high efficiency laboratories, offices, and support functions for energy-related research and development (R&D) in a new sustainable building. Efficient heating, ventilation, and air conditioning (HVAC) systems will be installed to support cutting edge research and the operation of sensitive instrumentation. The scope of the project includes design, construction, and start-up of the new facility, extension of existing site utilities to the new building, and demolition of a sufficient amount of excess facilities including building 185, to meet offsetting space requirements for the new building.

This type of space is limited at BNL and forces collaborative efforts into ad-hoc, sub-standard facilities which often limits the research. The proposed building will consolidate staff, improve employee moral, help retain and attract scientific talent, and improve capability to meet the DOE mission. This building will be designed to encourage peer interactions and collaborative visits by staff around the laboratory.

FY 2009 funds will be used for preliminary and final design and establishment of the performance baseline. FY 2010 funds will be used to continue construction activities.

The project is being conducted in accordance with the project management requirements in DOE O 413.3A Program and Project Management for the Acquisition of Capital Assets, and all appropriate project management requirements have been met.

## 5. Financial Schedule

(dollars in thousands)

| | Appropriations | Obligations | Recovery Act Costs | Costs |
|---|---|---|---|---|
| Total Estimated Cost (TEC) | | | | |
| PED[a] | | | | |
| FY 2009 | 8,240 | 8,240 | — | 4,000 |
| FY 2010 | — | — | — | 4,240 |
| Total, PED | 8,240 | 8,240 | — | 8,240 |

[a] All design will be completed in less than 18 months.

(dollars in thousands)

| | Appropriations | Obligations | Recovery Act Costs | Costs |
|---|---|---|---|---|
| Construction | | | | |
| FY 2009 Recovery Act | 18,673 | 18,673 | 500[a] | — |
| FY 2010 | 39,387 | 39,387 | 2,000 | — |
| Outyears | TBD | TBD | 16,173 | TBD |
| Total, Construction | TBD | TBD | 18,673 | TBD |
| | | | | |
| TEC | | | | |
| FY 2009 | 8,240 | 8,240 | — | 4,000 |
| FY 2009 Recovery Act | 18,673 | 18,673 | 500 | — |
| FY 2010 | 39,387 | 39,387 | 2,000 | 4,240 |
| Outyears | TBD | TBD | 16,173 | TBD |
| Total, TEC | TBD | TBD | 18,673 | TBD |
| | | | | |
| Other Project Cost (OPC)[b] | | | | |
| FY 2008 | 500 | 500 | — | 500 |
| Total, OPC | 500 | 500 | — | 500 |
| | | | | |
| Total Project Cost (TPC) | | | | |
| FY 2008 | 500 | 500 | — | 500 |
| FY 2009 | 8,240 | 8,240 | — | 4,000 |
| FY 2009 Recovery Act | 18,673 | 18,673 | 500 | — |
| FY 2010 | 39,387 | 39,387 | 2,000 | 4,240 |
| Outyears | TBD | TBD | 16,173 | TBD |
| Total, TPC | TBD | TBD[c] | 18,673 | TBD |

[a] Involves early site preparation activities as approved by the Acquisition Executive.
[b] Other project Costs of $500,000 are funded through laboratory overhead.
[c] This project has not yet received approval of CD-2; therefore, construction and TEC estimate displayed only include anticipated activities through FY 2010. Construction funds, other than for early site preparation activities, will not be executed.

## 6. Details of Project Cost Estimate

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| Total Estimated Cost (TEC) | | | |
| Design (PED) | | | |
| Design | 6,918 | 7,485 | N/A |
| Contingency | 1,322 | 755 | N/A |
| Total, PED | 8,240 | 8,240 | N/A |
| | | | |
| Construction | | | |
| Site Preparation | 1,500 | N/A | N/A |
| Other Construction | 46,817 | N/A | N/A |
| Contingency | 9,743 | N/A | N/A |
| Total, Construction | 58,060 | N/A | N/A |
| | | | |
| Total, TEC[a] | 66,300 | 8,240 | N/A |
| Contingency, TEC | 11,065 | 755 | N/A |
| | | | |
| Other Project Cost (OPC)[b] | | | |
| OPC except D&D | | | |
| Conceptual Planning | 50 | 50 | N/A |
| Conceptual Design | 450 | 383 | N/A |
| Start-Up | — | — | N/A |
| Contingency | — | 67 | N/A |
| Total, OPC except D&D | 500 | 500 | N/A |
| Contingency, OPC | — | 67 | |
| | | | |
| Total, TPC | 66,800 | 8,740 | N/A |
| Total, Contingency | 11,065 | 822 | N/A |

## 7. Schedule of Project Costs

For schedule of project costs, see Section 5, "Financial Schedule."

[a] This project has not yet received approval of CD-2; therefore, construction and TEC estimate displayed only include anticipated activities through FY 2010. Construction funds, other than for early site preparation activities, will not be executed without Acquisition Executive approval. The preliminary total estimated cost range is $61,300,000 to $66,300,000.

[b] Other Project Costs of $500,000 are funded through laboratory overhead.

## 8. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy (fiscal quarter or date) | 4 Q FY 2013 |
| Expected Useful Life (number of years) | 50 |
| Expected Future Start of D&D of this capital asset (fiscal quarter) | 4 Q FY 2063 |

## (Related Funding requirements)

(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | Current Total Estimate | Previous Total Estimate | Current Total Estimate | Previous Total Estimate |
| Operations | 16,500 | N/A | 660,000 | N/A |
| Maintenance | 1,500 | N/A | 60,000 | N/A |
| Total, Operations & Maintenance | 18,000 | N/A | 720,000 | N/A |

## 9. Required D&D Information

The project will demolish a sufficient amount of excess facilities to meet space offsetting requirements for the new building at the BNL site. The details of which specific buildings will be demolished will be developed as part of the performance baseline for CD-2.

## 10. Acquisition Approach

Design will be performed by an architect-engineer (A-E) firm with the subcontract managed by the BNL operating contractor. The A-E firm will be competitively selected based on qualifications. After completion of the design, the BNL operating contractor will solicit offers from prospective large and small business general construction firms and award a firm fixed price construction subcontract. Evaluation of bids will include consideration of each offeror's experience, safety record, and past performance in successfully completing similar construction projects. Award will then be made to the lowest priced, qualified, responsible, responsive bidder.

Site preparation, which includes clearing, utility isolation and relocation, and demolition of existing structures on the building site will be conducted under a separate subcontract to the BNL operating contractor. Demolition of excess facilities will be accomplished using either the BNL operating contractor's in-house resources or one of its basic ordering agreement subcontractors.

**09-SC-74, Technology & Engineering Development Facility, Thomas Jefferson National Accelerator Facility, Newport News, Virginia**
**Project Data Sheet is for PED/Construction**

## 1. Significant Changes

The most recent DOE O 413.3A approved Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range, which was approved on September 23, 2008 with a preliminary Total Estimated Cost (TEC) range of $66,000,000 to $72,200,000.

A Federal Project Director with certification level II has been assigned to this project.

This Project Data Sheet is a continuation of a PED PDS proceeding to construction.

## 2. Design, Construction, and D&D Schedule

(fiscal quarter or date)

| | CD-0 | CD-1 | (Design/PED Complete) | CD-2 | CD-3 | CD-4 | D&D Start | D&D Complete |
|---|---|---|---|---|---|---|---|---|
| FY 2009 | 09/18/2007 | 2Q FY 2009 | 3Q FY 2010 | 4Q FY 2009 | TBD | TBD | TBD | TBD |
| FY 2010 | 09/18/2007 | 09/23/2008[a] | 3Q FY 2010 | 4Q FY 2009 | TBD | TBD[b] | TBD | TBD |

CD-0 – Approve Mission Need
CD-1 – Approve Alternative Selection and Cost Range
CD-2 – Approve Performance Baseline
CD-3 – Approve Start of Construction
CD-4 – Approve Start of Operations or Project Closeout
D&D Start – Start of Demolition & Decontamination (D&D) work
D&D Complete –Completion of D&D work

## 3. Baseline and Validation Status

(dollars in thousands)

| | TEC, PED | TEC, Construction | TEC, Total[c] | OPC Except D&D[d] | OPC, D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2009 | 3,700 | TBD | TBD | 1,000 | TBD | TBD | TBD |
| FY 2010 | 3,700 | TBD | TBD | 1,000 | N/A | TBD | TBD |

## 4. Project Description, Justification, and Scope

The proposed project renovates Building 58 (the Test Lab, about 90,000 square feet), removes an estimated 7,000 to 10,000 square feet of inadequate and obsolete work space in and adjacent to the Test Lab, and allows for removal of between 2,000 and 12,000 square feet of dilapidated trailers that are characterized as inefficient, poor quality work environments that do not meet current commercial standards. The project also includes new construction which will add between 90,000 to 120,000 square

[a] The Department of Energy was under a continuing resolution for more than 5 months in FY 2009. As a result, this project did not receive PED funds and was not able to begin preliminary design until April 2009.
[b] The preliminary CD-4 range is 2QFY 2014 to 4QFY 2014.
[c] Costs are to be determined (TBD). Preliminary Total Estimated Cost (TEC) range is $66,000,000 to $72,000,000. No construction funds will be used until the performance baseline has been validated and CD-3 approved.
[d] Other Project Costs of $1,000,000 are funded through laboratory overhead.

feet of needed workspace for critical technical support functions including mechanical and electrical engineering, cryogenics engineering and fabrication, and environment, safety, and health. The scope will be finalized at CD-2.

The project will significantly improve the efficiency of workflow and provide a safer and sustainable work environment for multi-program functions such as Office of Science Superconducting Radio Frequency (SRF) R&D, multi-program cryomodule assembly and testing, and large accelerator and experimental equipment assembly. The project will implement functional efficiencies in areas such as clean rooms, chemistry facilities, high bays, laboratories, and office space. It also corrects numerous safety and building codes to ensure compliance and will reduce energy consumption of the existing building by approximately 30%. The design will incorporate all current applicable codes, standards, and best management practices. The design will meet sustainability principles and environmental, safety and health features, and will implement Integrated Safety Management at all levels per DOE Policy 225.1.

The approved TJNAF Secretarial Waiver (9/15/06) provides offsetting space for this project. The removal of about 10,000 square feet of inadequate and obsolete work space in and next to the 42-year-old Test Lab plus removal of about 12,000 square feet of dilapidated trailers will offset the space added by this project.

TJNAF has identified projects needed as a platform for the science and technology mission of the laboratory. SRF research and production is located in the Test Lab building, making correction of the performance gap in this building a high priority. The related engineering and support facilities to incorporate this technology into accelerator operations are equally important.

To enable further advancement of TJNAF state-of-the-art production processes, it is necessary to reconfigure the layout of all the laboratory, shop, clean room, and office areas to provide efficient and effective work flow and assure safe working conditions throughout the building. The Test Lab Rehabilitation along with construction of 90,000 to 120,000 square feet of additional technical space under this project will address many of these limitations by streamlining the production process, renovating or replacing obsolete infrastructure, relocating critical production and testing facilities to more appropriate locations, and consolidating emerging and development functions.

It is anticipated that as a result of TJNAF's reputation and expertise as a national SRF center of excellence, TJNAF will be used in the design and construction of cryomodules for future Office of Science accelerator projects. Renovation of the Test Lab will ensure that TJNAF facilities can reliably support production of advanced cryomodules with the quality required for future projects.

Mechanical and electrical systems over 40 years old contribute to the deteriorated condition of the Test Lab. Numerous components in these current systems are no longer commercially available. The building has never undergone a major rehabilitation of its systems or components. The three main air handlers serving the High Bay area are well past the end of their design life and a number of other air handlers installed in 1987 are nearing the end of their life cycles. The HVAC renovation included in this project will replace these systems and upgrade all systems to full electronic control, improving maintainability and energy management capabilities. The electrical systems are of the same vintage. As this equipment degrades and becomes unreliable, it poses increasing risk of fire or arc flash hazards. Renovation of the electrical distribution system as part of this project will increase safety and enable improved load distribution and flexibility for future power utilization.

Environmental management functions such as waste water treatment, waste acid neutralization, and air handling are complicated by the piecemeal evolution of the facilities with multiple systems of differing vintage trying to work together to maintain safe and environmentally responsible conditions. A significant portion of plumbing in the Test Lab remains from the original construction and needs rehabilitation to ensure future reliability of services and to assure integrity for dependable environmental protection.

Numerous work items are required to bring the Test Lab building up to current codes and standards. Many aspects of the building, while meeting code at the time of construction, do not meet current safety code standards, regulations, and practices. Currently, in order to comply with code requirements, administrative controls are required in certain work areas. To bring the building up to current safety and accessibility standards, a number of upgrades to stairways, walkways, guardrails, the fire alarm system, fire doors, fire walls, door hardware, and signage will be implemented as part of this project.

The work environment improvements provided by this project will increase staff morale working in areas not intended as work space such as in service buildings or in offices built on large concrete shielding enclosures with access by suspended walkways. This project will also enhance the laboratory's ability to attract and retain world-class scientists by providing a quality work environment. In addition, mechanical and electrical upgrades will result in reduced energy cost.

FY 2009 funds will be used to complete preliminary and final designs for both the new construction and the renovation work. FY 2010 construction funds will be used to start construction work on the new buildings, including project management and associated support activities.

The project is being conducted in accordance with the project management requirements in DOE O 413.3A, Program and Project Management for the Acquisition of Capital Assets, and all appropriate project management requirements have been met.

## 5. Financial Schedule

(dollars in thousands)

| | Appropriations | Obligations | Costs |
|---|---|---|---|
| Total Estimated Cost (TEC) | | | |
| PED | | | |
| FY 2009 | 3,700 | 3,700 | 1,900 |
| FY 2010 | — | — | 1,800 |
| Total, PED | 3,700 | 3,700 | 3,700 |
| Construction | | | |
| FY 2010 | 27,687 | 27,687 | 12,000 |
| Outyears | TBD | TBD | TBD |
| Total, Construction | TBD | TBD | TBD |
| TEC | | | |
| FY 2009 | 3,700 | 3,700 | 1,900 |
| FY 2010 | 27,687 | 27,687 | 13,800 |
| Outyears | TBD | TBD | TBD |
| Total, TEC | TBD | TBD | TBD |

(dollars in thousands)

| | Appropriations | Obligations | Costs |
|---|---|---|---|
| Other Project Cost (OPC)[a] | | | |
| OPC except D&D | | | |
| FY 2008 | 1,000 | 1,000 | 300 |
| FY 2009 | — | — | 700 |
| Total OPC except D&D | 1,000 | 1,000 | 1,000 |
| Total Project Cost (TPC) | | | |
| FY 2008 | 1,000 | 1,000 | 300 |
| FY 2009 | 3,700 | 3,700 | 2,600 |
| FY 2010 | 27,687 | 27,687 | 13,800 |
| Outyears | TBD | TBD | TBD |
| Total, TPC | TBD | TBD | TBD |

## 6. Details of Project Cost Estimate

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| Total Estimated Cost (TEC) | | | |
| Design (PED) | | | |
| Design | 3,350 | 3,515 | N/A |
| Contingency | 350 | 185 | N/A |
| Total, PED | 3,700 | 3,700 | N/A |
| Construction | | | |
| Site Preparation | 3,900 | N/A | N/A |
| Equipment | — | N/A | N/A |
| Other Construction | 18,187 | N/A | N/A |
| Contingency | 5,600 | N/A | N/A |
| Total Construction | 27,687 | N/A | N/A |
| Total, TEC[b] | TBD | 3,700 | N/A |
| Contingency, TEC | TBD | 185 | N/A |

[a] Other Project Costs of $1,000,000 are funded through laboratory overhead.
[b]This project has not yet received approval of CD-2; therefore, construction and TEC estimate displayed only include anticipated activities through FY 2010. Construction funds will not be executed without appropriate CD-2 and CD-3 approvals. The preliminary total estimated cost range for this project is $66,000,000 to $72,200,000.

| | (dollars in thousands) | | |
|---|---|---|---|
| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
| Other Project Cost (OPC)[a] | | | |
| OPC except D&D | | | |
| Conceptual Planning | 150 | 150 | N/A |
| Conceptual Design | 770 | 770 | N/A |
| Contingency | 80 | 80 | N/A |
| Total, OPC | 1,000 | 1,000 | N/A |
| Total, TPC[b] | TBD | 4,700 | N/A |
| Total, Contingency | TBD | 265 | N/A |

## 7. Schedule of Project Costs

For schedule of project costs, see Section 5, "Financial Schedule."

## 8. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | |
| New Construction | 4Q FY 2012 |
| Renovation | 4Q FY 2014 |
| Expected Useful Life | 50 years |
| Expected Future Start of D&D of this capital asset | 4Q FY 2064 |

## (Related Funding requirements)

| | (dollars in thousands) | | | |
|---|---|---|---|---|
| | Annual Costs | | Life Cycle Costs | |
| | Current Total Estimate | Previous Total Estimate | Current Total Estimate | Previous Total Estimate |
| Operations | 478 | N/A | 23,900 | N/A |
| Maintenance | 1,120 | N/A | 56,000 | N/A |
| Total, Operations & Maintenance | 1,598 | N/A | 79,900 | N/A |

## 9. Required D&D Information

The approved TJNAF Secretarial Waiver (9/15/06) provides offsetting space for this project. The removal of about 7,000 to 10,000 square feet of inadequate and obsolete work space in and next to the 42-year-old Test Lab plus removal of about 2,000 to 12,000 square feet of dilapidated trailers will help offset the space added by this project.

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[a] Other Project Costs of $1,000,000 are funded through laboratory overhead.

[b] This project has not yet received approval of CD-2; therefore, construction and TEC estimate displayed only include anticipated activities through FY 2010. Construction funds will not be executed without appropriate CD-2 and CD-3 approvals. The preliminary total estimated cost range for this project is $66,000,000 to $72,200,000.

## 10. Acquisition Approach

Design will be performed by an architect-engineer (A-E) firm with the subcontract managed by the TJNAF operating contractor, Jefferson Science Associates (JSA). The A-E subcontractor will be competitively selected based on the demonstrated competence and qualifications to perform the required design services at a fair and reasonable price.

After completion of the design, the TJNAF operating contractor will solicit offers from prospective large and small business general construction firms and award firm fixed price construction subcontract(s). Evaluation of offers will include consideration of each offeror’s relative experience and past performance in successfully completing similar construction projects. Award will then be made to the qualified responsible, responsive offeror that submits the lowest reasonable offer.

Construction management will be performed by a Construction Management company (CM) with the subcontract managed by the TJNAF operating contractor. The CM subcontractor will be competitively selected based on the demonstrated competence and qualifications of potential firms to perform the required services at a fair and reasonable price. The A-E subcontractor will be retained to assist when needed during the construction activity, preparation and analysis of changes, and review of submittals and other performance related documents.

## 07-SC-05, Physical Sciences Facility,
## Pacific Northwest National Laboratory (PNNL), Richland, Washington
## Project Data Sheet is for PED/Construction

### 1. Significant Changes

The most recent DOE O 413.3A approved Critical Decision (CD) is CD-3B, Approve Start of Construction—Balance of Construction, which was approved on April 16, 2008, with a Total Project Cost (TPC) of $224,000,000.

A Federal Project Director with a certification level II has been assigned to this project.

No Project Data Sheet (PDS) was submitted for this project in the FY 2008 budget. This PDS is an update of the FY 2009 PDS.

### 2. Design, Construction, and D&D Schedule

(fiscal quarter or date)

| | CD-0 | CD-1 | (Design/PED Complete) | CD-2 | CD-3A | CD-3B |
|---|---|---|---|---|---|---|
| FY 2007 | 09/23/2004 | 1Q FY 2006 | 1Q FY 2008 | 2Q FY 2007 | | 1Q FY 2008 |
| FY 2009 | 09/23/2004 | 12/15/2006 | 2Q FY 2008 | 06/22/2007 | 7/20/2007 | 2Q FY 2008 |
| FY 2010 | 09/23/2004 | 12/15/2006 | 11/1/2007 | 06/22/2007 | 7/20/2007 | 4/16/2008 |

CD-0 – Approve Mission Need
CD-1 – Approve Alternative Selection and Cost Range
CD-2 – Approve Performance Baseline
CD-3A – Site work, Foundations, and Steel
CD-3B – Approve Start of Construction

(fiscal quarter or date)

| | CD-4A | CD-4 | D&D Start | D&D Complete |
|---|---|---|---|---|
| FY 2007 | | 2Q FY 2011 | FY 2011 | FY 2015 |
| FY 2009 | 2Q FY 2010 | 2Q FY 2011 | FY 2011 | FY 2015 |
| FY 2010 | 2Q FY 2010 | 2Q FY 2011 | FY 2011 | FY 2015 |

CD-4A – Approve Start of Operations
CD-4B – Approve Start of Operations or Project Closeout
D&D Start – Start of Decontamination and Decommissioning (D&D) work
D&D Complete – Completion of D&D work

Decontamination and Decommissioning (D&D) activities for the facilities being vacated in the 300 Area will be conducted under a separate project managed by EM.

## 3. Baseline and Validation Status

(dollars in thousands)

| | TEC, PED | TEC, Construction | TEC, Total | OPC, Except D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|
| FY 2007 | 25,000-35,000 | 155,000–210,000 | 180,000–245,000 | 20,000–25,000 | 20,000–25,000 | 200,000–270,000 |
| FY 2009 | 29,486 | 180,443 | 209,929 | 14,071 | 14,071 | 224,000 |
| FY 2010 | 29,486 | 181,417 | 210,903 | 13,097 | 13,097 | 224,000 |

## 4. Project Description, Justification, and Scope

This project, the line-item construction element of the Pacific Northwest National Laboratory (PNNL) Capability Replacement Laboratory (CRL) projects, will be used to construct new laboratory and office space on the PNNL site north of Horn Rapids Road (also referred to as the Horn Rapids Triangle) and to complete life extension upgrades to the 325 Building to accommodate a portion of the existing research capabilities being displaced as a result of the closure and cleanup of facilities in the Hanford 300 Area. The buildings to be constructed or modernized by this project are listed below.

- 3410 Building—Materials Science and Technology
- 3410 Building—Chemistry and Processing
- 3420 Building—Radiation Detection
- 3425 Building—Ultra-low Background/Deep Laboratory
- 3430 Building—Ultra-trace
- 3440 Building—Large Detector Laboratory
- 325 Building (Radiochemical Processing Laboratory)—Shielded Operations

The balance of research capabilities accounted for in the CRL will be housed in leased facilities and in three other existing 300 Area buildings (Buildings 318, 331, and 350) in the southern portion of the 300 Area that DOE’s Office of Science (SC) will also retain. Several ancillary support facilities, including a fire station, a telephone switch, and internet node will also be retained.

The new facilities listed above (i.e., all except the 325 Building) will constitute approximately 190,000 square feet of new construction to accommodate the following mission critical capabilities: materials science and technology, radiation detection, ultra-trace, and chemistry and processing (non-nuclear). The facilities will include laboratory and office space to house appropriate equipment and staff suited for each of these purposes. New construction on the Horn Rapids Triangle will also include a central utility plant, a paved outdoor area for experimental capabilities to detect radiological materials in vehicles and containers, and a large detector laboratory.

To support increased heating, ventilation, and air conditioning (HVAC) capacity requirements, modernization of the 325 Building will include removal of fume hoods and design, fabrication, and installation of new hot cells and glove boxes. In addition, repairs and other upgrades will be performed to allow continued use of the facility.

The estimate provided is based on design development to support CD-2 and reflects approved changes implemented in accordance with a certified earned value management system (EVMS). Project Engineering and Design (PED) funds were received in FY 2004, 2005, and 2006. The FY 2006 appropriation provided additional PED funds to complete project engineering and design and to initiate construction. Construction began in FY 2007 with initiation of site work. FY 2008 funds were utilized to award and initiate the foundation and structural steel and balance of facility construction activities on both the new construction and 325 Building Life Extension upgrades. This project data sheet is requesting construction funds in FY 2010 to continue those efforts.

SC, the National Nuclear Security Administration (NNSA), and the Department of Homeland Security (DHS) are jointly funding the PSF project. The allocation of costs among the three project sponsors was determined based upon the estimated net square footage of space required to perform research in support of each sponsor's mission needs, as identified in the Justification of Mission Need. Sponsor shares of the Total Project Cost (TPC) will be as follows: SC, 44 percent; NNSA, 31 percent; DHS, 25 percent. On November 7, 2006, SC, NNSA, and DHS formally established a funding strategy with the purpose, to the extent funding is appropriated and available, of providing a predictable funding profile, critical to finishing this project on schedule and within budget.

Currently, more than 4,000 PNNL staff members conduct and support research activities on a consolidated laboratory campus composed of 79 buildings with nearly two million square feet of space. Approximately one-third of that space (about 700,000 square feet) is located in the Hanford Site 300 Area—a National Priorities List waste site of aging, cold war facilities targeted by DOE for an aggressive cleanup effort to reduce costs and accelerate site closure. Facilities in the 300 Area represent 45 percent of PNNL's experimental laboratory space and house many capabilities important to accomplishing DOE strategic objectives.

DOE, which operates PNNL and the Hanford Site, the U. S. Environmental Protection Agency, and the State of Washington, signed a comprehensive cleanup and compliance agreement on May 15, 1989. This Hanford Federal Facility Agreement and Consent Order, or Tri-Party Agreement, established enforceable regulatory milestones for the cleanup of the site including the completion of surplus facility disposition and remedial action clean-up of the Hanford Site 300 Area by 2015. The DOE Office of Environmental Management (EM), the office responsible for executing the Hanford 300 Area cleanup project has determined that the most efficient and economical method of cleanup will entail wholesale removal of the surplus buildings and underground utility systems to get at and remove the contamination. Limited transition out of the 300 Area is already underway, and PNNL staff and equipment have already been removed from several of the facilities and relocated to a newly leased office building and existing laboratory space. Facilities currently occupied by PNNL that are not to be retained by the laboratory will all be vacated in 2011 and available for cleanup.

SC programs at PNNL support research in chemical, materials, and environmental sciences, systems biology, atmospheric sciences, and climate change. The capabilities required include expertise and programs in biology, low-dose radiation biology, environmental molecular chemistry, microbiology, biogeochemistry, subsurface science, systems biology, and biotechnology. These capabilities are needed to solve some of the nation's most pressing problems in energy production, carbon sequestration, national security, and environmental remediation.

NNSA strategically invests in science, technology, and infrastructure to develop the essential capabilities to accomplish its mission. In support of the NNSA mission, PNNL conducts science, technology, and analytic activities in the 300 Area to prevent the proliferation of weapons of mass destruction, promote international nuclear safety, ensure compliance with international arms control treaties, and protect the nation's critical infrastructure. The ultra-low-level radionuclide detection and characterization analytical laboratory provides a national asset to the NNSA user community. The

PNNL staff skills, experience, and research equipment in the 300 Area are an integral part of the NNSA nonproliferation activities.

DHS strategically invests in facilities to support its research needs and to develop and maintain the essential capabilities to accomplish its mission. PNNL will continue to provide research capabilities to DHS in the ultra-trace, radiation detection, information analysis, certification, systems biology, chemistry, and processing capabilities.

FY 2006 and FY 2007 construction funds were used for Horn Rapids Triangle site work, foundations, and structural steel. FY 2008 construction funds were used to begin construction on the Horn Rapids Triangle facilities and 325 Building modifications. FY 2009 funds will be used to complete construction and modifications.

The project is being conducted in accordance with the project management requirements in DOE O 413.3A and DOE M 413.3-1, Program and Project Management for the Acquisition of Capital Assets, and all appropriate project management requirements have been met. The most recent DOE O 413.3A approved Critical Decision (CD) is CD-3B, Approve Start of Construction – Balance of Construction, which was approved on April 16, 2008.

## 5. Financial Schedule[a]

(dollars in thousands)

| | Appropriations | | | | Obligations | | | | Costs | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | NNSA | SC | DHS | Total | NNSA | SC | DHS | Total | NNSA | SC | DHS | Total |
| Total Estimated Costs | | | | | | | | | | | | |
| PED | | | | | | | | | | | | |
| FY 2004 | — | 986 | — | 986 | — | 986 | — | 986 | — | — | — | — |
| FY 2005 | — | 4,960 | 2,000 | 6,960 | — | 4,960 | 2,000 | 6,960 | — | — | — | — |
| FY 2006 | 12,870 | 2,970 | — | 15,840 | 12,870 | 2,970 | — | 15,840 | 742 | 3,710 | 2,000 | 6,452 |
| FY 2007 | 3,700 | — | 2,000 | 5,700 | 3,700 | — | 2,000 | 5,700 | 12,392 | 5,206 | — | 17,598 |
| FY 2008 | — | — | — | — | — | — | — | — | 3,436 | — | 2,000 | 5,436 |
| Total, PED | 16,570 | 8,916 | 4,000 | 29,486 | 16,570 | 8,916 | 4,000 | 29,486 | 16,570 | 8,916 | 4,000 | 29,486 |

[a] DHS is expected to fund 25 percent, or $55,933,000, of the Total Project Cost for this project, with the remaining portion funded by DOE. This Financial Schedule is based on assumed funding contributions agreed to in the Memorandum of Understanding (MOU) among the funding parties.

(dollars in thousands)

| | Appropriations | | | | Obligations | | | | Costs | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | NNSA | SC | DHS | Total | NNSA | SC | DHS | Total | NNSA | SC | DHS | Total |
| Construction | | | | | | | | | | | | |
| FY 2006 | — | 1,980 | — | 1,980 | — | 1,980 | — | 1,980 | — | — | — | — |
| FY 2007 | 4,220 | 10,000 | — | 14,220 | 4,220 | 10,000 | — | 14,220 | — | 1,219 | — | 1,219 |
| FY 2008 | 24,772 | 24,773 | 13,511 | 63,056 | 24,772 | 24,773 | 13,511 | 63,056 | 11,779 | 13,519 | 5,964 | 31,262 |
| FY 2009 | 18,460 | 52,775 | 21,717 | 92,952 | 18,460 | 52,775 | 21,717 | 92,952 | 24,962 | 51,619 | 26,972 | 103,553 |
| FY 2010 | — | — | 7,525 | 7,525 | — | — | 7,525 | 7,525 | 8,220 | 19,794 | 7,828 | 35,842 |
| FY 2011 | — | — | 1,684 | 1,684 | — | — | 1,684 | 1,684 | 2,491 | 3,377 | 3,673 | 9,541 |
| Total, Construction | 47,452 | 89,528 | 44,437 | 181,417 | 47,452 | 89,528 | 44,437 | 181,417 | 47,452 | 89,528 | 44,437 | 181,417 |
| | | | | | | | | | | | | |
| Total TEC | | | | | | | | | | | | |
| FY 2004 | — | 986 | — | 986 | — | 986 | — | 986 | — | — | — | — |
| FY 2005 | — | 4,960 | 2,000 | 6,960 | — | 4,960 | 2,000 | 6,960 | — | — | — | — |
| FY 2006 | 12,870 | 4,950 | — | 17,820 | 12,870 | 4,950 | — | 17,820 | 742 | 3,710 | 2,000 | 6,452 |
| FY 2007 | 7,920 | 10,000 | 2,000 | 19,920 | 7,920 | 10,000 | 2,000 | 19,920 | 12,392 | 6,425 | — | 18,817 |
| FY 2008 | 24,772 | 24,773 | 13,511 | 63,056 | 24,772 | 24,773 | 13,511 | 63,056 | 15,215 | 13,519 | 7,964 | 36,698 |
| FY 2009 | 18,460 | 52,775 | 21,717 | 92,952 | 18,460 | 52,775 | 21,717 | 92,952 | 24,962 | 51,619 | 26,972 | 103,553 |
| FY 2010 | — | — | 7,525 | 7,525 | — | — | 7,525 | 7,525 | 8,220 | 19,794 | 7,828 | 35,842 |
| FY 2011 | — | — | 1,684 | 1,684 | — | — | 1,684 | 1,684 | 2,491 | 3,377 | 3,673 | 9,541 |
| Total, TEC | 64,022 | 98,444 | 48,437 | 210,903 | 64,022 | 98,444 | 48,437 | 210,903 | 64,022 | 98,444 | 48,437 | 210,903 |
| | | | | | | | | | | | | |
| Other Project Costs (OPC) | | | | | | | | | | | | |
| OPC except D&D | | | | | | | | | | | | |
| FY 2004 | 600 | — | 250 | 850 | 600 | — | 250 | 850 | — | — | — | — |
| FY 2005 | 5,000 | — | — | 5,000 | 5,000 | — | — | 5,000 | 3,201 | — | 232 | 3,433 |
| FY 2006 | — | — | — | — | — | — | — | — | 1,135 | — | — | 1,135 |
| FY 2007 | — | — | — | — | — | — | — | — | 352 | — | — | 352 |
| FY 2008 | — | — | 1,489 | 1,489 | — | — | 1,489 | 1,489 | 442 | — | — | 442 |
| FY 2009 | — | — | 3,283 | 3,283 | — | — | 3,283 | 3,283 | 470 | — | 4,788 | 5,258 |
| FY 2010 | — | — | 2,475 | 2,475 | — | — | 2,475 | 2,475 | — | — | 2,464 | 2,464 |
| FY 2011 | — | — | — | — | — | — | — | — | — | — | 13 | 13 |
| Total, OPC | 5,600 | — | 7,497 | 13,097 | 5,600 | — | 7,497 | 13,097 | 5,600 | — | 7,497 | 13,097 |

(dollars in thousands)

| | Appropriations | | | | Obligations | | | | Costs | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | NNSA | SC | DHS | Total | NNSA | SC | DHS | Total | NNSA | SC | DHS | Total |
| Total Project Cost (TPC) | | | | | | | | | | | | |
| FY 2004 | 600 | 986 | 250 | 1,836 | 600 | 986 | 250 | 1,836 | — | — | — | — |
| FY 2005 | 5,000 | 4,960 | 2,000 | 11,960 | 5,000 | 4,960 | 2,000 | 11,960 | 3,201 | — | 232 | 3,433 |
| FY 2006 | 12,870 | 4,950 | — | 17,820 | 12,870 | 4,950 | — | 17,820 | 1,877 | 3,710 | 2,000 | 7,587 |
| FY 2007 | 7,920 | 10,000 | 2,000 | 19,920 | 7,920 | 10,000 | 2,000 | 19,920 | 12,744 | 6,425 | — | 19,169 |
| FY 2008 | 24,772 | 24,773 | 15,000 | 64,545 | 24,772 | 24,773 | 15,000 | 64,545 | 15,657 | 13,519 | 7,964 | 37,140 |
| FY 2009 | 18,460 | 52,775 | 25,000 | 96,235 | 18,460 | 52,775 | 25,000 | 96,235 | 25,432 | 51,619 | 31,760 | 108,811 |
| FY 2010 | — | — | 10,000 | 10,000 | — | — | 10,000 | 10,000 | 8,220 | 19,794 | 10,292 | 38,306 |
| FY 2011 | — | — | 1,684 | 1,684 | — | — | 1,684 | 1,684 | 2,491 | 3,377 | 3,686 | 9,554 |
| Total, TPC | 69,622 | 98,444 | 55,934 | 224,000 | 69,622 | 98,444 | 55,934 | 224,000 | 69,622 | 98,444 | 55,934 | 224,000 |

## 6. Details of Project Cost Estimate

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| Total Estimated Cost (TEC) | | | |
| Design (PED) | | | |
| Design | 29,486 | 29,466 | 28,241 |
| Contingency | — | 20 | 1,377 |
| Total, PED | 29,486 | 29,486 | 29,618 |
| Construction | | | |
| Site Preparation (General Site Work Package) | 3,308 | 4,501 | 4,577 |
| Equipment (standard building equipment included in Other Construction below) | — | — | — |
| Other Construction | 162,825 | 142,128 | 140,621 |
| Contingency | 15,284 | 33,814 | 35,057 |
| Total, Construction | 181,417 | 180,443 | 180,255 |
| Total, TEC | 210,903 | 209,929 | 209,873 |
| Contingency, TEC | 15,284 | 33,834 | 36,434 |

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| Other Project Cost (OPC) | | | |
| OPC except D&D | | | |
| Conceptual Design | 4,165 | 4,165 | 4,165 |
| Start-Up | 8,161 | 7,906 | 7,658 |
| Contingency | 771 | 2,000 | 2,304 |
| Total, OPC | 13,097 | 14,071 | 14,127 |
| Contingency, OPC | 771 | 2,000 | 2,304 |
| Total, TPC | 224,000 | 224,000 | 224,000 |
| Total, Contingency | 16,055 | 35,834 | 38,738 |

## 7. Schedule of Project Costs

For schedule of project costs, see Section 5, "Financial Schedule."

## 8. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy (fiscal quarter or date) | 2Q FY 2010 |
| Expected Useful Life (number of years) | 20 years (existing facilities)<br>40 years (new facilities) |
| Expected Future Start of D&D of this capital asset (fiscal quarter) | 2Q FY 2050 |

## (Related Funding requirements)

(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | Current Total Estimate | Previous Total Estimate | Current Total Estimate | Previous Total Estimate |
| Operations | 6,000 | 6,000 | 395,000 | 395,000 |
| Maintenance | 3,700 | 3,700 | 245,000 | 245,000 |
| Total, Operations & Maintenance | 9,700 | 9,700 | 640,000 | 640,000 |

## 9. Required D&D Information

This project involves construction of a new facility and completion of upgrades to the 325 Building to house capabilities being displaced by the closure of the 300 Area of the Hanford Site in Richland, Washington. As described in Section 4, the D&D costs are being funded by the EM program over the next 8–10 years and are not included in this estimate.

| | Square Feet |
|---|---|
| Area of new construction | ~190,000 |
| Area of existing facility(s) being replaced | ~400,000 |
| Area of additional D&D space to meet the "one-for-one" requirement | N/A |

Name and site location of existing facility to be replaced: PNNL-occupied facilities in the 300 Area of the Hanford Site in Richland, Washington.

## 10. Acquisition Approach

Design and inspection of the facilities and equipment will be conducted by the operating contractor and architectural-engineering subcontractor as appropriate. Technical construction is being done by a competitively-bid lump-sum contract administered by PNNL. To the extent feasible, construction and procurement is being accomplished by fixed-price contracts awarded on the basis of competitive bidding. Project and construction management, inspection, coordination, testing and checkout witnessing, and acceptance will be performed by the PNNL operating contractor.

## Science Program Direction

### Funding Profile by Category

| | (dollars in thousands/whole FTEs) | | | |
|---|---|---|---|---|
| | FY 2008 Current Appropriation | FY 2009 Original Appropriation | FY 2009 Additional Appropriation[a] | FY 2010 Request |
| Science Program Direction | | | | |
| Salaries and Benefits | 129,428 | 138,781 | — | 155,924 |
| Travel | 3,811 | 4,618 | — | 5,227 |
| Support Services | 22,815 | 19,018 | +1,100 | 24,306 |
| Other Related Expenses | 21,725 | 24,278 | +500 | 28,265 |
| Total, Science Program Direction | 177,779 | 186,695 | +1,600 | 213,722 |
| Full Time Equivalents[bc] | 981 | 1,066 | — | 1,149 |

## Program Overview

### Mission

The mission of the Science Program Direction (SCPD) program is to provide and sustain a skilled and motivated Federal workforce to provide oversight for taxpayer dollars used to support energy and science-related investments for the Office of Science (SC). The SC workforce is responsible for overseeing taxpayer dollars for science program development; implementation and execution; and operation, administrative, business, technical, and program management. Through the Office of Scientific and Technical Information (OSTI), the SC workforce aids in providing access to the DOE's research and development (R&D) results.

### Background

The increased attention to energy independence, nuclear security, scientific discovery and innovation, and environmental protection has and will continue to impact the SC in dramatic ways. The SC directly funds, oversees, and manages science programs that focus on research in global climate change, environmental improvements, electrical energy storage, advanced nuclear fuel cycle, fusion energy sources, matter and energy components, and the evolution of nuclear matter.

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[a] The Additional Appropriation column reflects the planned allocation of funding from the American Recovery and Reinvestment Act of 2009, P.L. 111–5. See the Department of Energy Recovery website at http://www.energy.gov/recovery for up-to-date information regarding Recovery Act funding.

[b] FY 2008 data for Full Time Equivalent (FTE) employment reflects actual usage, whereas FY 2009 and FY 2010 reflect FTE ceilings. The FY 2008 FTE ceiling, based on the FY 2008 appropriation and as reflected in the FY 2009 Budget Request to Congress, was 1,058. Actual usage was lower than the ceiling in FY 2008 due primarily to deferred backfills of vacancies and other hiring due to uncertainty over the timing and levels of FY 2008 and FY 2009 appropriations. The FY 2009 appropriation includes the transfer of 8 FTEs from the Office of Nuclear Energy, so the FY 2009 FTE ceiling is flat at 1,066.

[c] Responsibility for the New Brunswick Laboratory was transferred in FY 2008 to SC from the former Office of Security and Safety Performance Assurance. Therefore all FY 2008 funding ($6,644,000) and FTEs (28) are reflected in SC. However, 9 of the 28 FTEs are reflected in the Other Defense Activities appropriation account in the Appendix volume of the President's budget. .

The SC workforce is essential to the future of energy and scientific advances. With an experienced workforce, SC effectively administers and accomplishes its individual program goals. As a result, SC effectively aids in achieving DOE goals and the goals of the Nation.

- The SC Headquarters (HQ) Federal workforce is responsible for SC-wide issues, oversight, and scientific program development and management across a broad spectrum of scientific disciplines and program offices. Working in collaboration with the laboratory and university communities, the SC HQ Federal staff makes a major contribution by setting the policies and direction for DOE science investment and providing oversight of that investment.
- Field personnel are responsible for implementing the SC program within the framework established by HQ policy, direction, and guidance. Site Office staff, located at each of the ten SC laboratories, are responsible for the day-to-day oversight of over $3 billion per year management and operating contract performance of the SC laboratories.
- The Integrated Support Center (ISC) provided by staff at the Chicago and Oak Ridge (OR) Offices offer administrative, business, and technical support across the entire SC enterprise. These operations include field support in areas such as financial management; human resources (HR); grant and contract processing; safety, security, and health management; labor relations, intellectual property and patent management; environmental compliance; infrastructure operations maintenance; and information systems development and support.
- Federal staff at OSTI fulfills the Department’s legislative mandate to provide public access to the unclassified results of DOE’s research programs. OSTI also collects, protects, and provides secure access to DOE’s classified research outcomes. Recognizing that science research is also performed in other federal agencies and, indeed, at counterpart organizations around the world, OSTI has built broad collaborations both within the U.S. and internationally to enable a single point of access to nearly 400 million pages of scientific information. Within the U.S., Science.gov offers simultaneous searching of federal science databases and websites, while WorldWideScience.org performs the same functionality across the R&D results of over 50 countries. By facilitating and accelerating access to such information, SC is accelerating scientific discovery itself.

In order to meet the increasing workload and expectations of its science programs, it is essential to ensure the SC is adequately staffed and balanced with appropriate skills, education, and experience. SC will complete a comprehensive Workload/Workforce Analysis Study that will indentify workload indicators and their relationship to staffing requirements and budget allocations. This study will include an examination of current workforce demographics, statistical trends over time, forecasts for projecting attrition and retirement, and best practice comparisons to similar science agencies.

### Benefits

Society and the American economy will benefit tremendously from a safe and enduring energy future. To accomplish this, SC programs must continue to administer their scientific projects that focus on these developments. In order for SC programs to function effectively, SCPD must provide and fund an adequate staff and management for its science programs. As a result, SCPD’s contribution to the SC mission will ultimately move our society closer to these fundamental changes in energy and science.

### Budget Overview

The FY 2010 budget request fully supports and provides for a federal workforce with the capability to manage the significantly increased investment in energy and science-related research. The FY 2010 request includes salaries, benefits, travel, training, and associated expenses for 1,149 full time equivalents (FTEs), an increase of 83 FTEs or an 8% increase over the FY 2009 FTE ceiling of 1,066.

The increased SC research, construction, and general plant project funding in FY 2009 and FY 2010 creates a substantial workload across numerous workforce areas, including but not limited to grants, contracts, finance, legal, construction and infrastructure management, and environment, safety, and health (ES&H) as well as significant management, oversight, and reporting challenges across the complex.

Total SC funding has grown $1,140,592,000, an annualized growth rate of 9.5% from FY 2006 to FY 2009. In contrast, SCPD funding increased at an annualized growth rate of 5.4% ($27,577,000). The average research portfolio of a HQ Program Manager is estimated to increase 52.9% during FY 2009. The FY 2010 budget request increases SC funding an additional $169,364,000, which results in an 8.0% annualized growth from FY 2006 to FY 2010. The increase to the SCPD FY 2010 request is $27,027,000 that results in a 7.7% annualized growth from FY 2006 through FY 2010, comparable to the overall growth of the SC program and a growth driven by the increased taxpayer investment in energy and science research and Administration goals and priorities. Staffing shortages in the HQ Program Offices have been previously identified; since FY 2002, 17 Committee of Visitors (COV) reports have cited the need for additional Program Managers and support staff at HQ for virtually all Program Offices. SC HQ Program and Project Managers also assist other DOE technology programs with merit and project reviews. Grant and contract awards are estimated to increase by more than 40% over FY 2008, placing significant demands on the current acquisition workforce at HQ and the Field. Increased funding allotments and accelerated execution of those allotments will place greater financial management and accountability responsibilities on program, budget, financial, and accounting offices across the complex. Additional construction projects and general plant projects will require greater project management and facility and safety oversight. These are but a few of the challenges facing the current SC workforce.

Since FY 2007, the onboard SC federal workforce has grown from 968 to 990, or 2.3%. This slow growth rate is primarily due to deferred backfills of vacancies and other deferred hiring due to uncertainties related to the SCPD FY 2008 and FY 2009 appropriations. The increasing need for federal management, transparency, professional business operations, and highly skilled project management requires both an increased workforce and a SCPD budget that keeps pace with growth in science program funding. For that reason, SC plans to hire up to the FY 2009 FTE ceiling level of 1,066, which is the same as the FY 2008 FTE ceiling of 1,058, accounting for the 8 FTEs transferred from the DOE Office of Nuclear Energy in FY 2009, as reflected in the FY 2009 President's Request to Congress.

The SC succession planning has been impacted by the decreased FY 2008 and FY 2009 SCPD appropriations. The average age of current SC employees is 51 years old and 301 employees (31%) are eligible for voluntary retirement by FY 2010. The requested growth in SCPD appropriations will allow SC to effectively plan for retirements, replenish critical positions, and provide an adequate and appropriately skilled workforce to meet SC goals and missions.

## Detailed Justification

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| **Salaries and Benefits** | **129,428** | **138,781** | **155,924** |

Salaries and benefits funding for FY 2010 supports 1,149 Federal FTEs: 431 FTEs at HQ, which includes employees based in Germantown, Maryland, and Washington, DC; and 718 FTEs at the Site offices and the ISC, which includes employees located throughout the U.S.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |

The 83 additional new FTEs requested in FY 2010 include:

- 53 additional Program Manager and support staff FTEs for the SC HQ Program Offices to ensure that the necessary resources and infrastructure exists to facilitate sound scientific program development, management, oversight, and reporting of a significantly increased SC research program. These additional FTEs will address staffing concerns cited in 17 COV reports since FY 2002, as well as address succession planning and development.
- 30 additional staff FTEs across the SC Field complex will ensure that acquisition (grants and contracts), financial, HR, legal, health, safety, security, facilities management, and other necessary infrastructure is in place to fully support the SC enterprise, ensure contractor oversight, and address succession planning and development.

Strategically deployed recruitment, relocation, and retention bonuses will be employed corporately to attract and retain technically skilled and highly qualified employees.

| | | | |
|---|---|---|---|
| **Travel** | **3,811** | **4,618** | **5,227** |

Travel includes all transportation, subsistence, and incidental travel expenses of SC's Federal employees and Advisory Committee members in accordance with Federal Travel Regulations. Funding is also included for travel costs associated with permanent change of station (PCS).

Federal staff travel is required to effectively manage a broad spectrum of scientific disciplines and perform contractor oversight at geographically dispersed facilities. The purpose is to ensure implementation of DOE orders and regulatory requirements, and includes attendance at site, project, and program reviews; internal audits, compliance reviews, and oversight of investigations and administrative proceedings; operational policy and process reviews and meetings; conferences; and training for skill maintenance and/or certification.

The request also includes travel expenses for over 150 members making up the six individual SC advisory committees. Committee membership primarily consists of representatives from universities, national laboratories, and industry and includes a diverse balance of disciplines, experiences, and geography. Each of the six advisory committees meets three to four times annually and provides valuable, independent advice to the Department regarding the complex scientific and technical issues that arise in the planning, management, and implementation of the SC programs.

| | | | |
|---|---|---|---|
| **Support Services** | **22,815** | **19,018** | **24,306** |

Support services includes contracts to provide both technical expertise and general administrative services and activities as follows:

- Maintenance, operation, and cyber security management of SC HQ, OSTI, and the field mission-specific information management systems and infrastructure and SC-corporate Enterprise Architecture and Capital Planning Investment Control management. Provides for a one-time upgrade to the Energy Sciences Network (ESnet).
- Accessibility to DOE's multi-billion dollar R&D program through E-Gov information systems managed and administered by OSTI.
- Operations and maintenance of the Searchable Field Work Proposal (FWP) system to provide HQ and Field organizations a tool to search, evaluate, and monitor both legacy and current FWPs.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|

(dollars in thousands)

- Day-to-day operations, including mailroom services, travel processing, administration of the Small Business Innovation Research (SBIR) program, grants and contract close-out activities, copy centers, directives coordination, and filing and retrieving records.
- Training and education of federal staff, including continuing education and career development training.
- Reports or analyses directed toward improving the effectiveness, efficiency, and economy of management and general administrative services.
- Staffing for 24-hour emergency communications centers and safeguards and security (S&S) oversight functions.
- Energy research analysis, studies, and activities relevant to DOE's energy and science missions.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **Other Related Expenses** | **21,725** | **24,278** | **28,265** |

Other related expenses provides funding for SC's contributions to the Working Capital Fund (WCF) established at DOE HQ to allocate the costs of common Departmental HQ administrative services to the recipient organizations. Services provided include rent and building operations, telecommunications (telephone services), network connectivity, supplies/equipment, printing/graphics, photocopying, mail and postage, contract closeout and purchase card surveillance; operation and maintenance of the Standard Accounting and Reporting System (STARS), and the Strategic Integrated Procurement Enterprise System (STRIPES); contractor support for the Payments Processing Center at the OR Financial Service Center; and Office of Management and Budget Circular A-123 reporting requirements support.

WCF services assessed to and used by both HQ and the Field include the following:

- Online corporate training services
- Payroll processing
- Corporate Human Resource Information System (CHRIS)
- Project Management Career Development Program (PMCDP)

Expenses in the Field include fixed requirements associated with rent, utilities, and telecommunications and are paid directly, as are requirements such as building and grounds maintenance, computer/video maintenance and support, printing and graphics, copier leases, site-wide health care units, and equipment.

Storage of household goods and the buying/selling of homes in conjunction with directed PCS moves are included for HQ and the field as well as E-Gov fees for various initiatives such as the Integrated Acquisition Environment and E-Travel.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **Total, Science Program Direction** | **177,779** | **186,695** | **213,722** |

## Explanation of Funding Changes

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| **Salaries and Benefits** | |
| Provides support for a net increase of 83 FTEs over FY 2009. Most of these new hires are assumed to be onboard by early to mid-FY 2010. Assumes a 2.0% pay raise for 2010; 5.1% escalation for personnel/pay related activities such as benefits for health insurance and retirement; and an increased cap for Senior Executive Service basic pay. | +17,143 |
| **Travel** | |
| Provides support for travel requirements related to additional Program Managers and increased program management oversight of a significantly increased SC research portfolio at HQ (+$408,000); increased travel requirements by technical and administrative staff supporting acquisitions, finance, ES&H, and training certifications and qualifications (+$201,000). | +609 |
| **Support Services** | |
| Maintains current level of support services for maintenance, operation, and increased cyber security management of SC HQ mission-specific information management systems and infrastructure and energy research analyses and studies (+$911,000); and supports a one-time upgrade to the ESnet (+$343,000).<br><br>The increase also maintains current level of management support services (+$1,727,000) in the field to include technical support for Documented Safety Analyses and occupational medicine, S&S oversight services; safety related projects, health physics, emergency operations, criticality support, financial reviews of SBIR proposals, statistical support, and administrative support such as mail and file services and security processing/declassification; maintains current level of information technology (IT) support (+$2,349,000); and supports training requirements for current staff (+$288,000).<br><br>Offsetting the increases are decreases to development costs associated with the Searchable FWP (-$160,000) and allocation of training support costs by lead Program Secretarial Office (SC-OR Office) to the user (Office of Environmental Management) (-$170,000). | +5,288 |
| **Other Related Expenses** | |
| Supports increases in the WCF related to space, communications, utilities, supplies, and other non-WCF services to support the additional FTEs to be hired in FY 2010 (+$2,094,000); and HQ IT operations and maintenance and purchase of equipment, including equipment related to a one-time upgrade to the ESnet (+$227,000). The increase also maintains the current level of Field and Site Office other services and fixed requirements such as building operations, utilities, communications, etc. (+$1,613,000); and technology refresh/update of Site Office IT equipment (+$53,000). | +3,987 |
| **Total Funding Change, Science Program Direction** | **+27,027** |

## Supporting Information

## Operating Expenses, Capital Equipment and Construction Summary

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Operating Expenses | 177,579 | 186,695 | 213,722 |
| Capital Equipment | 200 | — | — |
| Total, Science Program Direction | 177,779 | 186,695 | 213,722 |

## Funding Profile by Category by Site

| | (dollars in thousands/whole FTEs) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| **Headquarters** | | | |
| Salaries and Benefits | 49,919 | 47,445 | 56,659 |
| Travel | 2,283 | 2,872 | 3,268 |
| Support Services | 10,292 | 9,911 | 11,220 |
| Other Related Expenses | 10,892 | 12,997 | 15,459 |
| Total, Headquarters | 73,386[a] | 73,225 | 86,606 |
| Full Time Equivalents | 312[a] | 321 | 374 |
| | | | |
| **Office of Scientific and Technical Information** | | | |
| Salaries and Benefits | — | 6,571 | 6,673 |
| Travel | — | 84 | 86 |
| Support Services | — | 1,207 | 1,103 |
| Other Related Expenses | — | 1,054 | 1,054 |
| Total, Office of Scientific and Technical Information | — | 8,916 | 8,916 |
| Full Time Equivalents | —[a] | 57 | 57 |
| | | | |
| **Field Offices** | | | |
| Chicago Office | | | |
| Salaries and Benefits | 21,989 | 25,253 | 26,326 |
| Travel | 393 | 425 | 541 |
| Support Services | 2,536 | 471 | 4,019 |
| Other Related Expenses | 1,798 | 688 | 2,714 |
| Total, Chicago Office | 26,716 | 26,837 | 33,600 |
| Full Time Equivalents | 187 | 197 | 204 |

[a] Starting in FY 2009, OSTI is a separate line. FY 2008 OSTI amounts are $9,220,000 and 55 FTEs and non-OSTI HQ amounts are $64,166,000 and 257 FTEs.

| | (dollars in thousands/whole FTEs) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Oak Ridge Office | | | |
| Salaries and Benefits | 30,964 | 32,116 | 30,168 |
| Travel | 498 | 695 | 536 |
| Support Services | 7,122 | 6,246 | 6,192 |
| Other Related Expenses | 4,690 | 5,891 | 5,409 |
| Total, Oak Ridge Office | 43,274[a] | 44,948[a] | 42,305 |
| Full Time Equivalents | 296[a] | 291[a] | 261 |
| Ames Site Office | | | |
| Salaries and Benefits | 489 | 503 | 585 |
| Travel | 21 | 25 | 28 |
| Support Services | 22 | 33 | 5 |
| Other Related Expenses | 55 | 39 | — |
| Total, Ames Site Office | 587 | 600 | 618 |
| Full Time Equivalents | 4 | 4 | 4 |
| Argonne Site Office | | | |
| Salaries and Benefits | 3,377 | 3,476 | 4,194 |
| Travel | 21 | 47 | 49 |
| Support Services | 208 | 190 | 56 |
| Other Related Expenses | 595 | 215 | — |
| Total, Argonne Site Office | 4,201 | 3,928 | 4,299 |
| Full Time Equivalents | 23 | 24 | 28 |

[a] Starting in FY 2010, the Oak Ridge National Laboratory Site Office (ORNLSO) is proposed as a separate line. In FY 2008 and FY 2009, ORNLSO funding is included within Oak Ridge (OR) Office funding. FY 2008 ORNLSO amounts are $3,344,000 and 22 FTEs, and OR amounts are $39,930,000 and 274 FTEs. FY 2009 ORNLSO amounts are $4,357,000 and 31 FTEs, and OR amounts are $40,591,000 and 260 FTEs.

| | (dollars in thousands/whole FTEs) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Berkeley Site Office | | | |
| Salaries and Benefits | 3,326 | 3,748 | 4,234 |
| Travel | 79 | 107 | 87 |
| Support Services | 787 | 68 | 103 |
| Other Related Expenses | 452 | 39 | 143 |
| Total, Berkeley Site Office | 4,644 | 3,962 | 4,567 |
| Full Time Equivalents | 21 | 25 | 27 |
| | | | |
| Brookhaven Site Office | | | |
| Salaries and Benefits | 3,444 | 3,714 | 4,606 |
| Travel | 87 | — | 110 |
| Support Services | 190 | — | 360 |
| Other Related Expenses | 574 | — | 360 |
| Total, Brookhaven Site Office | 4,295 | 3,714 | 5,436 |
| Full Time Equivalents | 22 | 27 | 29 |
| | | | |
| Fermi Site Office | | | |
| Salaries and Benefits | 2,162 | 2,240 | 2,494 |
| Travel | 54 | 54 | 63 |
| Support Services | 62 | 76 | 80 |
| Other Related Expenses | 234 | 46 | 58 |
| Total, Fermi Site Office | 2,512 | 2,416 | 2,695 |
| Full Time Equivalents | 15 | 15 | 17 |
| | | | |
| New Brunswick Laboratory | | | |
| Salaries and Benefits | 3,541 | 3,392 | 4,478 |
| Travel | 131 | 73 | 55 |
| Support Services | 1,079 | 327 | 518 |
| Other Related Expenses | 1,893 | 2,791 | 1,930 |
| Total, New Brunswick Laboratory | 6,644 | 6,583 | 6,981 |
| Full Time Equivalents | 28 | 29 | 35 |

| | (dollars in thousands/whole FTEs) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Oak Ridge National Laboratory Site Office | | | |
| Salaries and Benefits | — | — | 3,982 |
| Travel | — | — | 64 |
| Support Services | — | — | 333 |
| Other Related Expenses | — | — | 60 |
| Total, Oak Ridge National Laboratory Site Office | —[a] | —[b] | 4,439 |
| Full Time Equivalents | —[b] | —[b] | 31 |
| | | | |
| Pacific Northwest Site Office | | | |
| Salaries and Benefits | 4,769 | 4,671 | 5,062 |
| Travel | 137 | 65 | 159 |
| Support Services | 147 | 75 | 110 |
| Other Related Expenses | 133 | 453 | 819 |
| Total, Pacific Northwest Site Office | 5,186 | 5,264 | 6,150 |
| Full Time Equivalents | 35 | 35 | 38 |
| | | | |
| Princeton Site Office | | | |
| Salaries and Benefits | 1,615 | 1,691 | 1,920 |
| Travel | — | 35 | 45 |
| Support Services | 1 | — | 12 |
| Other Related Expenses | 224 | — | 78 |
| Total, Princeton Site Office | 1,840 | 1,726 | 2,055 |
| Full Time Equivalents | 12 | 12 | 13 |
| | | | |
| Stanford Site Office | | | |
| Salaries and Benefits | 2,195 | 2,224 | 2,556 |
| Travel | 53 | 61 | 56 |
| Support Services | 142 | 402 | 157 |
| Other Related Expenses | 109 | 61 | 61 |
| Total, Stanford Site Office | 2,499 | 2,748 | 2,830 |
| Full Time Equivalents | 14 | 16 | 16 |

[a] Starting in FY 2010, Oak Ridge National Laboratory Site Office (ORNLSO) is proposed as a separate line. In FY 2008 and FY 2009, ORNLSO funding is included within the Oak Ridge (OR) Office funding. FY 2008 ORNLSO amounts are $3,344,000 and 22 FTEs, and OR amounts are $39,930,000 and 274 FTEs. FY 2009 ORNLSO amounts are $4,357,000 and 31 FTEs, and OR amounts are $40,591,000 and 260 FTEs.

| (dollars in thousands/whole FTEs) | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| Thomas Jefferson Site Office | | | |
| Salaries and Benefits | 1,638 | 1,737 | 1,987 |
| Travel | 54 | 75 | 80 |
| Support Services | 227 | 12 | 38 |
| Other Related Expenses | 76 | 4 | 120 |
| Total, Thomas Jefferson Site Office | 1,995 | 1,828 | 2,225 |
| Full Time Equivalents | 12 | 13 | 15 |
| **Total Field Offices** | | | |
| Salaries and Benefits | 79,509 | 84,765 | 92,592 |
| Travel | 1,528 | 1,662 | 1,873 |
| Support Services | 12,523 | 7,900 | 11,983 |
| Other Related Expenses | 10,833 | 10,227 | 11,752 |
| Total, Field Offices | 104,393 | 104,554 | 118,200 |
| Full Time Equivalents | 669 | 688 | 718 |
| **Total SCPD** | | | |
| Salaries and Benefits | 129,428 | 138,781 | 155,924 |
| Travel | 3,811 | 4,618 | 5,227 |
| Support Services | 22,815 | 19,018 | 24,306 |
| Other Related Expenses | 21,725 | 24,278 | 28,265 |
| Total, SCPD | 177,779 | 186,695 | 213,722 |
| Full Time Equivalents[ab] | 981 | 1,066 | 1,149 |

[a] FY 2008 data for Full Time Equivalent (FTE) employment reflects actual usage, whereas FY 2009 and FY 2010 reflect FTE ceilings. The FY 2008 FTE ceiling, based on the FY 2008 appropriation and as reflected in the FY 2009 Budget Request to Congress, was 1,058. Actual usage was lower than the ceiling in FY 2008 due primarily to deferred backfills of vacancies and other hiring due to uncertainty over the timing and levels of FY 2008 and FY 2009 appropriations. The FY 2009 appropriation includes the transfer of 8 FTEs from the Office of Nuclear Energy, so the FY 2009 FTE ceiling is flat at 1,066.
[b] Responsibility for the New Brunswick Laboratory was transferred in FY 2008 to SC from the former Office of Security and Safety Performance Assurance. Therefore all FY 2008 funding ($6,644,000) and FTEs (28) are reflected in SC. However, 9 of the 28 FTEs are reflected in the Other Defense Activities appropriation account in the Appendix volume of the President’s budget.

## Support Services by Category

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Technical Support | | | |
| Development of Specifications | 520 | 258 | 146 |
| System Definition | 356 | 192 | 183 |
| System Review and Reliability Analyses | 520 | 510 | 521 |
| Total, Technical Support | 1,396 | 960 | 850 |
| Management Support | | | |
| Automated Data Processing | 10,651 | 5,541 | 9,339 |
| Training and Education | 716 | 1,053 | 1,270 |
| Reports and Analyses Management and General Administrative Services | 10,052 | 11,464 | 12,847 |
| Total, Management Support | 21,419 | 18,058 | 23,456 |
| Total, Support Services | 22,815 | 19,018 | 24,306 |

## Other Related Expenses by Category

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Other Related Expenses | | | |
| Rent to GSA | 242 | 810 | 825 |
| Rent to Others | — | 614 | 460 |
| Communications, Utilities, and Miscellaneous | 1,943 | 2,083 | 2,355 |
| Printing and Reproduction | 27 | 17 | 96 |
| Other Services | 6,230 | 6,900 | 7,239 |
| Operation and Maintenance of Equipment | 664 | 1,040 | 1,331 |
| Operation and Maintenance of Facilities | 2,123 | 1,930 | 2,071 |
| Supplies and Materials | 1,731 | 661 | 1,479 |
| Equipment | 2,140 | 1,729 | 1,804 |
| Working Capital Fund | 6,625 | 8,494 | 10,605 |
| Total, Other Related Expenses | 21,725 | 24,278 | 28,265 |

## Workforce Development for Teachers and Scientists

### Funding Profile by Subprogram

(dollars in thousands)

| | FY 2008 Current Appropriation | FY 2009 Original Appropriation | FY 2009 Additional Appropriation[a] | FY 2010 Request |
|---|---|---|---|---|
| Workforce Development for Teachers and Scientists | | | | |
| Student Programs | 4,760 | 5,265 | — | 8,078 |
| Educator Programs | 2,664 | 6,311 | — | 5,750 |
| Workforce Development Programs | — | — | +12,500 | 5,000 |
| Program Administration and Evaluation | 620 | 2,007 | — | 1,850 |
| Total, Workforce Development for Teachers and Scientists | 8,044 | 13,583 | +12,500 | 20,678 |

**Public Law Authorizations:**
Public Law 95–91, "Department of Energy Organization Act", 1977
Public Law 101–510, "DOE Science Education Enhancement Act," 1991
Public Law 103–382, "The Albert Einstein Distinguished Educator Fellowship Act of 1994"
Public Law 109–58, "Energy Policy Act of 2005"
Public Law 110–69, "America COMPETES Act of 2007"

## Program Overview

### Mission

The mission of the Workforce Development for Teachers and Scientists (WDTS) program is to help ensure that DOE and the Nation have a sustained pipeline of highly trained Science, Technology, Engineering, and Mathematics (STEM) workers.

### Background

The U.S. STEM workforce is part of the foundation upon which our Nation's prosperity is built. Trillions of dollars of investments in the Nation's 1,540 independent school districts, 1,700 community colleges, and 2,500 four-year colleges and universities have resulted in an educational system that annually produces thousands of students who are prepared for STEM careers and the emerging innovation economy.

New dynamics, however, could weaken the U.S. STEM workforce. Foreign students educated in the U.S. are increasingly going to our foreign competitors, who employ these highly trained students in their own laboratories and factories, drawing away a source of skilled workers the U.S. had captured in the past. Other nations are establishing universities and training facilities that match U.S. capabilities and are attracting students who otherwise would come to the U.S. Even though demographic shifts in the U.S. indicate that the U.S. will be a majority population of minorities by 2043, U.S. students,

[a] The Additional Appropriation column reflects the planned allocation of funding from the American Recovery and Reinvestment Act of 2009, P.L. 111–5. See the Department of Energy Recovery website at http://www.energy.gov/recovery for up-to-date information regarding Recovery Act funding.

particularly students from under-represented populations, are not choosing STEM careers and educations.

The Nation is not in crisis, but as the National Academy of Sciences' 2005 report, "Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Future," indicates, the warning signs are on the horizon. Without investments in U.S. STEM workforce and education, the U.S. is in danger of becoming less competitive in the increasingly innovative, knowledge-based global economy.

DOE and its predecessor organizations have been involved with STEM workforce training and education for over 60 years. These programs have produced tens of thousands of world class scientists, engineers, and technicians who have helped solve national security, energy, and environment challenges, while pursuing answers to many of the most important scientific questions in physics, biology, and other areas of basic science. DOE's STEM education programs are primarily executed through DOE national laboratories and several major research universities that work with the Department, and these programs typically involve mentor-intensive research training.

WDTS works closely with DOE national laboratory education offices to implement a range of workforce and education opportunities for STEM students and faculty. These programs include world class competitions, such as the National Science Bowl®, which annually attracts 22,000 of the highest achieving middle and high school students in the Nation; undergraduate internship opportunities at the DOE national laboratories, which place over 750 students each year in mentor-intensive research environments; and K–12 and undergraduate faculty professional development programs that place more than 300 educators into DOE-sponsored research programs.

**Subprograms**

WDTS is organized into four subprograms: Students, Educators, Workforce Development, and Program Administration and Evaluation.

- The *Student* subprogram focuses on encouraging students to enter STEM careers and retaining them in the workforce. Competitions at the middle school and high school levels are designed to reward and recognize high-potential science and engineering students. At the undergraduate level, WDTS places students into world class research environments to improve their content knowledge and to help them understand how to be successful as researchers. Included within this subprogram are Science Undergraduate Laboratory Internship (SULI), Community College Institute (CCI), Pre-Service Teachers (PST), the National Science Bowl®, and the Real World Design Challenge.
- The *Educator* subprogram provides professional development experiences for K–12 and undergraduate faculty teaching STEM subjects. Faculty are provided with two mentor-intensive experiences: one in a research setting working on a DOE research project, and another under the tutelage of a master teacher or senior laboratory staff to understand how to translate lessons learned in the laboratory into classroom practice and content. Included within this subprogram are DOE Academies Creating Teacher Scientists (ACTS), Faculty and Student Teams (FaST), and the Albert Einstein Distinguished Educator Fellowship.
- The *Workforce Development* subprogram is new for FY 2010 and is designed to bring top talent into the Nation's STEM workforce. A new graduate fellowship program will support high-potential students studying physics, biology, chemistry, mathematics, and other disciplines important to DOE's missions in energy, environment, national security, and basic discovery, and nurture the skills needed to pursue careers at universities, industry, DOE national laboratories, and in the Federal government.

- The *Program Administration and Evaluation* subprogram develops and deploys rigorous evaluation methods for all WDTS programs; sponsors longitudinal workforce studies that track student and educator participants in DOE programs; encourages partnerships with Federal agencies, industry, academic institutions, and professional associations to leverage resources and expertise in workforce development; and improves DOE outreach efforts to communicate to the broader public the role the Department plays in STEM education and the opportunities that are available to students and educators, particularly those from under-served populations. Included within this subprogram are the Laboratory Equipment Donation Program, Evaluation Studies, Technology Development and On-Line Application Systems, Outreach, Workforce Studies, and the DOE Mentor Program.

**Benefits**

WDTS delivers three major benefits to society, which are closely tied to the need to improve the overall STEM workforce in the U.S.

First, students and educators who otherwise might not have selected a STEM career/education are provided opportunities through WDTS competitions, internships, and other activities to make an informed choice about pursuing a STEM career. Given the need for the U.S. to increase the supply of highly technical workers, increasing the overall pool of potential students and educators is critical.

Second, students and faculty with an aptitude and desire to pursue STEM careers and education are introduced through WDTS programs to authentic research environments and mentors as a way to increase the retention of students and faculty in STEM fields. Very few educators at the K–12 level have ever worked in a laboratory setting and this prevents them from effectively conveying to their students content knowledge and the process of science. In addition, studies[a] demonstrate that students and faculty who are exposed to mentor intensive research environments are much more likely to stay in the STEM system because of the support that is developed in those environments. This is important to society because there is a low retention rate of STEM students and K–12 educators, particularly those from under-represented populations.

Finally, WDTS provides students and faculty with a pathway to STEM careers at the Department, its national laboratories, and other institutions that support scientific disciplines consistent with DOE's missions in energy, environment, national security, and scientific discovery. Producing more STEM workers and educators results in considerable societal benefits, such as improvements in the performance of U.S. student academic performance, increases in the capabilities of faculty to teach STEM, the creation of a skilled scientific and technical workforce ready for high-wage job opportunities in the U.S. in emerging technical fields such as sustainable energy production, and improvements in the general public's understanding of the importance of DOE science and technology in their lives and society.

**Program Planning and Management**

The foundation for WDTS program planning and management efforts came through a series of stakeholder meetings in 2007–2009 that set a new direction for WDTS STEM workforce and education efforts. More than 100 representatives from other Federal agencies, the DOE national laboratories, scientific professional associations, education groups, universities, the private sector and organizations representing under-represented populations have provided WDTS with advice and comments. This

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[a] Bragg, D.D., *Promising Outcomes for Tech Prep Participants in Eight Local Consortia: A Summary of Initial Results***,** Minneapolis, MN: National Research Center for Career and Technical Education, University of Minnesota, 2001.

resulted in the development of a strategic plan[a] that serves as the blueprint that WDTS follows when setting its strategic direction. As a result of this effort, the WDTS program has been restructured to include:

- Rigorous evaluation of all WDTS programs
- Expansion of efforts to provide STEM professional development opportunities for K–12 and undergraduate faculty
- Programs for undergraduate students and educators that will fill critical skill gaps, with a premium on increasing the participation of under-represented populations and institutions in WDTS programs
- Implementation of two new initiatives consistent with recommendations from WDTS stakeholders: the Graduate Fellowship program and a dedicated mentoring program.

WDTS participates on the Education Subcommittee of the National Science and Technology Council (NSTC), which is managed by the White House Office of Science and Technology Policy (OSTP). Through the NSTC subcommittee and other venues, WDTS engages with the National Science Foundation (NSF), National Aeronautics and Space Administration (NASA), Department of Defense (DOD), National Institutes of Health (NIH), Federal Aviation Administration (FAA), and other Federal agencies to develop interagency efforts in science education. Recent examples include the creation of the Real World Design Challenge in cooperation with the FAA and co-sponsorship of Faculty and Student Teams (FaST) with NSF. In addition, WDTS has been participating in an effort within the NSTC's Education Subcommittee to outline a general interagency framework for science education.

WDTS programs have been reviewed by a panel of STEM experts and are recognized as premier opportunities offered by a Federal agency for students and faculty to become engaged in STEM fields. In addition, the review identified a number of "model" programs that other Federal agencies could adopt, for example, the National Science Bowl®, which attracts more than 22,000 of the highest performing middle and high school students in the Nation; the Academies Creating Teacher Scientists (ACTS) program; the Faculty and Student Teams (FaST) program, which integrates under-represented faculty into mainstream SC research programs; and, the Science Undergraduate Laboratory Internship (SULI) program, which is the flagship WDTS program and annually attracts 5–10 times more applicants than there are slots available.

**Coordination of Education/Workforce Development Activities**

WDTS coordinates with other DOE program offices to develop workforce and science education efforts that leverage existing WDTS capabilities and resources, particularly those developed within the DOE national laboratory system. WDTS has established programs and support infrastructure (online application system, outreach efforts, financial instruments, etc.) that interest other DOE programs seeking to create dedicated STEM education/workforce efforts. As a result, other DOE programs frequently consult with WDTS as they launch new efforts or propose partnerships that leverage resources.

In FY 2008–2009, for example, WDTS worked with the Office of Energy Efficiency and Renewable Energy (EERE) as they developed a plan for an FY 2010 workforce training and education initiative; the National Nuclear Security Administration (NNSA) as they developed a Faculty and Student Teams effort; the Office of Fossil Energy on a new undergraduate internship program; and the Office of

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[a] DOE Office of Workforce Development, *"Future Workforce Strategy,"* 2007.

Economic Impact and Diversity on mentor/protégé agreements with Historically Black Colleges and Universities. In addition, WDTS provides significant support for K–12 educator professional development and undergraduate internship programs at all three NNSA laboratories, the National Renewable Energy Laboratory (EERE), Idaho National Laboratory (Office of Nuclear Energy), and the Savannah River Ecology Laboratory (Office of Environmental Management).

**Budget Overview**

WDTS programs are designed to help the U.S. maintain its competitive edge. These opportunities will help increase the pipeline of skilled scientists and engineers who can successfully pursue careers in areas that will transform the world's energy and environment future, supports our national security, and seeks to understand the fundamentals of matter and energy itself. The FY 2010 budget request continues support for all ongoing program activities, including expanded support for the ACTS, FaST, CCI, Outreach, and Workforce Studies programs, and implements the new Graduate Fellowship and DOE Mentor programs.

**Significant Program Shifts**

The proposed Graduate Fellowship program will create an immediate pipeline of graduate students pursuing advanced science and engineering degrees with an interest in energy, environment, and basic research. Fellowship awards will be made on a competitive basis for a period of three years contingent on the Fellow's progress.

In addition, WDTS will significantly increase funding for the Science Undergraduate Laboratory Internship and Community College Institute programs.

## Student Programs

### Funding Schedule by Activity

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Student Programs | | | |
| Science Undergraduate Laboratory Internship | 2,583 | 2,800 | 4,000 |
| Community College Institute of Science and Technology | 319 | 292 | 800 |
| Pre-Service Teachers | 188 | 210 | 428 |
| National Science Bowl® | 1,670 | 1,963 | 2,350 |
| Real World Design Challenge | — | — | 500 |
| Total, Student Programs | 4,760 | 5,265 | 8,078 |

### Description

The goals of the Student subprogram are to provide mentor-intensive research experiences at the DOE national laboratories for students to enhance their content knowledge in science and mathematics and their investigative expertise, to inspire interest in pursuing STEM careers and K–12 STEM education, and to retain these students within the STEM pipeline. By providing a wide variety of students with the opportunity to work directly with many of the world's best scientists and use the most advanced scientific facilities available, this program expands the Nation's supply of highly skilled scientists and engineers, especially in the physical sciences where the greatest demand lies because of a steady decline in U.S. citizens entering these fields. Through the National Science Bowl® and other student science and engineering competitions, DOE's laboratories and facilities provide experiences to inspire secondary students to continue and focus on STEM education and careers.

### Selected FY 2008 Accomplishments

- In FY 2008, WDTS validated, through program evaluation, that undergraduate research experiences at the DOE national laboratories significantly increased a student's interest in pursuing a STEM career and that their content knowledge in STEM fields of importance to DOE increased as a result of the experience. These evaluation findings validated the WDTS approach to STEM workforce development, which relies heavily upon mentored research experiences.
- Peer review evaluation of more than 600 undergraduate student scientific abstracts from the research conducted by undergraduate students supported by WDTS indicates that students are participating in highly technical research projects under the close supervision of a senior laboratory scientist, which is a leading indicator that WDTS undergraduate programs are succeeding in their goal of promoting effective mentor/protégé relationships.
- WDTS teamed with the California State University (CSU) system in 2008 to create the "Student Teachers as Researchers" (STAR) program supported by CSU, which builds on the WDTS Pre-Service Teacher program and promotes life-long professional development for K–12 STEM educators. This is one example of how WDTS programs and resources can be leveraged for improving K–12 educator professional development sponsored by other organizations.
- FY 2008 marked the 18th anniversary of the DOE's National Science Bowl®. More than 16,000 high school students from over 1,500 school districts (10 percent of the U.S. total) participated in 67

regional science bowl events. Saturday science seminars at the National Science Bowl® introduced students to many contemporary issues and findings in contemporary scientific research. More than 5,000 volunteers participated in judging, timekeeping, and other activities helped make this event possible. The Middle School Science Bowl (MSSB), initiated in FY 2002 with 8 teams, expanded to 36 regional events with each winning team traveling to the national event. In addition to the academic competition, each middle school team participated in the Hydrogen Fuel Cell Car Challenge. In total, more than 6,000 students and 2,000 volunteers participated at the regional competitions. The national event was hosted by the National Renewable Energy Laboratory at the University of Denver.

## Detailed Justification

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| **Science Undergraduate Laboratory Internship** | **2,583** | **2,800** | **4,000** |

Science Undergraduate Laboratory Internship (SULI) supports a diverse group of students at DOE's national laboratories in individually mentored research experiences. Through these unique and highly focused experiences, students become a part of the national laboratory community and a source of talent for DOE and the Nation. Students in the program apply on a competitive basis and are matched with mentors working in the student's fields of interest, interest, spend an intensive 10–16 weeks working under the individual mentorship of resident scientists, produce a peer-reviewed abstract and research paper, and attend seminars that broaden their view of science careers and help them understand how to become members of the scientific community. Goals and outcomes are measured based on students' research papers and abstracts, pre- and post-surveys, and an annual evaluation by a group of peers, both within and outside of DOE. An undergraduate student journal is produced annually that publishes selected full length peer-reviewed research papers and all abstracts of SULI students. Full research papers published in the journal are presented by the student authors at a poster competition at the annual meeting of the American Association for the Advancement of Science (AAAS). An annual competition first held in 2008, the Science and Energy Research Challenge (SERCh), recognizes the 15 best posters produced by SULI students through a rigorous and peer reviewed selection process. The abstracts of the research conducted by these students and their mentors are posted on the AAAS web site. NSF collaborates with DOE to offer students in its undergraduate programs access to individually mentored research internships that they would otherwise not have. This activity helps ensure a steady flow of students with growing interest in science careers into the Nation's pipeline of workers at the national laboratories, academia, and industry.

In FY 2008, with DOE, NSF, and other leveraged support, 16 students participated in the fall semester program, 26 students participated in the spring semester program, and 370 students participated in the summer, with 22 from NSF programs. The DOE contribution will support an estimated 365 students in FY 2009 and 570 in FY 2010. This total includes undergraduate students who participate in the WDTS Faculty and Student Teams (FaST) program.

| | | | |
|---|---|---|---|
| **Community College Institute of Science and Technology** | **319** | **292** | **800** |

The Community College Institute (CCI) of Science and Technology, which provides a 10 to 16-week (summer or semester) mentored research internship at a DOE national laboratory for highly motivated community college students, is designed to address DOE's workforce shortages, particularly at the skilled technician level for DOE mission critical areas, such as “green technology” deployment. Because community colleges account for over 40% of the entire Nation’s undergraduate enrollment and a majority of under-represented students in STEM, this is a largely untapped and clear avenue to increase participation by under-represented groups in STEM careers. CCI students apply online and are matched with mentors working in the student’s field of interest, spend an intensive 10 weeks working under the individual mentorship of resident scientists, produce an abstract and formal research paper, and, attend professional enrichment activities, workshops, and seminars that broaden their view of career options, help them understand how to become members of the scientific community, and enhance their professional skills. Goals and outcomes are measured based on students’ research papers and abstracts, pre- and post-surveys, and external evaluation. An undergraduate student journal was created to publish selected full research papers and all abstracts of students in this activity.

Through the partnership with NSF, 13 undergraduate students in NSF programs (e.g., the Louis Stokes Alliance for Minority Participation and Advanced Technology Education program) also participated in CCI in FY 2008. In FY 2008, 48 DOE-supported students directly participated in this internship. Twelve additional students were part of one of the NSF programs that provided funding for CCI. WDTS will fund an estimated 48 students in FY 2009 and 115 students in FY 2010. This total includes students participating on FaST teams.

| | FY 2008 | FY 2009 | FY 2010 |
| --- | --- | --- | --- |
| **Pre-Service Teachers** | **188** | **210** | **428** |

The Pre-Service Teachers (PST) program prepares undergraduate students for a K–12 STEM education career. This effort addresses the national need to improve the content knowledge of STEM educators prior to entering the teaching workforce and to improve the retention rate of those educators once they enter the field (which has a 50% dropout rate after the first five years). The NSF has been a partner with DOE on this activity since FY 2001. This allows NSF’s undergraduate pre-service programs to include a PST internship in the opportunities they provide to students. Students in this program apply on a competitive basis and are matched with mentors working in the student’s field of interest; spend an intensive 10 weeks working under the mentorship of a master teacher and DOE laboratory scientist to help maximize the building of content knowledge and skills through the research experience; produce an abstract and an educational module related to their research and an optional research paper, poster, or oral presentation; and attend professional enrichment activities, workshops, and seminars that help students apply what they learn to their academic program and the classroom, help them understand how to become members of the scientific community, and improve their communication and other professional skills. Goals and outcomes are measured based on students’ abstracts, education modules, pre- and post-surveys, and external evaluation.

In FY 2008, 8 DOE national laboratories hosted 31 participating students (7 from NSF). In FY 2009, WDTS funding will support 35 students at 8 national laboratories. In 2010, the increase in funding will support 60 students and 6 master teachers at 10 DOE national laboratories.

| | FY 2008 | FY 2009 | FY 2010 |
| --- | --- | --- | --- |
| **National Science Bowl®** | **1,670** | **1,963** | **2,350** |

The National Science Bowl® is an internationally recognized, prestigious academic event for high school and middle school students. It has attained its level of recognition and participation through a grass-roots design, which encourages the voluntary participation of professional scientists, engineers, and educators from across the Nation. Students answer questions on topics in astronomy, biology, chemistry, mathematics, and physics in a highly competitive, Jeopardy-style format. From 1991–2009,

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |

nearly 200,000 students from across the Nation have participated in regional and national competitions and have been encouraged to excel in mathematics and science and to pursue careers in those fields. The National Science Bowl® provides students and educators with a forum to receive recognition for their talent and hard work by solving academic problems in selected fields of science and math, in addition to their participation in various hands-on science challenges. In 2009, both the high school and middle school teams that win their regional events will attend the four-day national finals held in Washington, D.C. During this time, the students participate in a day of scientific seminars and science discovery activities with the students "doing" science, with the event culminating in an academic competition. Middle school teams participate in the model hydrogen fuel cell car competition. WDTS funding provides all of the travel and lodging expenses for each winning team attending the national event, seminar speakers, trophies, awards, and items and equipment for the various hands-on and interactive science activities and events.

The number of regional events remains relatively constant from one year to the next with 67 to 70 high school and 36 to 40 middle school teams participating in recent years. A total of 22,000 middle and high school students participate at the regional and national competitions, along with more than 7,000 coaches and volunteers.

| | | | |
|---|---|---|---|
| **Real World Design Challenge** | **—** | **—** | **500** |

The Real World Design Challenge (RWDC) originated out of the National Science Bowl® high school engineering competition and was funded as a pilot effort in FY 2009. The National Science Bowl® focuses on basic research knowledge, but for five years students also participated in an engineering challenge (typically a fuel car competition) as part of the competition. Evaluation of the program indicated that a more rigorous engineering competition was needed to attract the Nation's best engineering students and to provide a real learning experience for the students. WDTS partnered in FY 2009 with a major computer-aided design (CAD) and computer-aided manufacturing (CAM) engineering software firm, the Federal Aviation Administration and several industry leaders to develop a pilot RWDC effort involving 10 states that culminated in a national competition held at the National Air and Space Museum in March 2009. WDTS will seek to expand the RWDC model to include participation from 15 additional states in FY 2010.

| | | | |
|---|---|---|---|
| **Total, Student Programs** | **4,760** | **5,265** | **8,078** |

### Explanation of Funding Changes

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| **Science Undergraduate Laboratory Internship** | |
| The number of students participating in this program increases by 635 in FY 2010, from 365 in FY 2009 to a total of 570 in FY 2010, with much of the growth focused on under-represented populations. | +1,200 |

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| **Community College Institute of Science and Technology** | |
| The number of students participating in this program increases by 67 in FY 2010, from 48 in FY 2009 to 115, reflecting WDTS's effort to meet the growing demand for "green technology" workers at DOE national laboratories. | +508 |
| **Pre-Service Teachers** | |
| The number of students participating in this program will increase by 25 in FY 2010, from 35 in FY 2009 to 60 students and 6 master teachers, which support WDTS's efforts to take the STAR K–12 educator professional development model to at least one new state. | +218 |
| **National Science Bowl®** | |
| Support is increased to provide fuel cell kits needed for the middle school competition. | +387 |
| **Real World Design Challenge** | |
| Support for travel, lodging, and associated activities**.** | +500 |
| **Total Funding Change, Student Programs** | **+2,813** |

## Educator Programs

### Funding Schedule by Activity

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Educator Programs | | | |
| DOE Academies Creating Teacher Scientists | 1,849 | 3,768 | 3,750 |
| Faculty and Student Teams | 250 | 1,543 | 1,000 |
| Albert Einstein Distinguished Educator Fellowship | 565 | 1,000 | 1,000 |
| Total, Educator Programs | 2,664 | 6,311 | 5,750 |

### Description

Improving the ability of educators at all levels to serve as mentors and teach science content is the key to increasing the size and quality of the STEM workforce. Laboratory research experiences are an effective approach to meet this goal[a]. WDTS has built programs at the K–12 and undergraduate levels that focus on increasing educator knowledge of DOE science and technology programs and missions, and provides them with the resources that enable them to be successful in the classroom.

The DOE Academies Creating Teacher Scientists (DOE ACTS) program is the platform from which WDTS launches its long-term relationships with K–12 educators. DOE ACTS is a STEM educator professional development program for middle and high school teachers. The program is designed around best practices in professional development as outlined from educational research and program improvements based upon evaluation data. Through DOE ACTS, educators improve their content knowledge in areas of high importance to DOE missions and become contributing researchers in the scientific community. As highly trained leaders in STEM education, they are a key element of the effort to reform our Nation's science education and to improve the quality of classroom educators.

The Faculty and Student Teams (FaST) program is WDTS's premier mechanism to bring under-represented faculty and students into the mainstream of DOE's research enterprise. FaST provides individual faculty, their students, and their respective institutions the training needed to successfully compete for Federal science research grants and to develop a deeper understanding of DOE science.

The Albert Einstein Distinguished Educator Fellowship benefits Federal agencies and Congressional offices as these outstanding educators provide their "real world" classroom expertise and advice to national policy makers. After their Fellowship, the educators return to their school districts or to education policy positions better prepared to be leaders at the local, regional, and national levels, and bring knowledge of Federal programs that provide resources to their school districts.

### Selected FY 2008 Accomplishments

- In FY 2008, WDTS, partnering with the California State University (CSU) system, helped pioneer the CSU "Science Teacher and Researcher" program. This innovative program brings together the long-standing success of the WDTS Pre-Service Teachers program with CSU's emerging K–12 STEM educator professional development program to build a life-long learning and support system

[a] Gilmer, P.J.; Hahn, L.; and Spaid, M.R.; *Experiential Learning for Pre-Service Science and Mathematics Teachers: Applications to Secondary Classrooms,* Tallahassee, FL: SERVE, 2002.

for K–12 educators. Forty pre-service educators supported by CSU participated in the first year model which, through evaluation, has proven successful in its goals.

- DOE ACTS participants in FY 2008 reported in evaluation surveys that their content knowledge in physics, chemistry, and geophysics increased by more than 20 percent, on average, a key indicator that the program is succeeding in embedding key science content that is important to DOE/SC into K–12 classrooms.
- In FY 2008, approximately 50% of WDTS FaST university faculty members received competitively awarded funding for research grants from DOE and the National Science Foundation. A key indicator of success for FaST is the ability of faculty to integrate within the Nation's research enterprise. Since the program began, more than 40 FaST faculty have submitted more than 100 research proposals to Federal institutions/agencies.

## Detailed Justification

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| **DOE Academies Creating Teacher Scientists** | **1,849** | **3,768** | **3,750** |

DOE ACTS requires a three-year commitment by educators to participate in this program. Each educator spends an intensive 4 to 8 weeks annually at DOE national laboratories working under the mentorship of master educators and laboratory scientists to build content knowledge, research skills, and a lasting connection with the scientific community through the research experience. Master educators, who are expert K–12 educators and adept in both scientific research and scientific writing, act as liaisons between the mentor scientists and the educator participants. This helps the educators transfer the research experiences to their classrooms. Follow-on support is considered critical. Participants receive an $800 per week stipend plus travel and housing expenses while at the national laboratories.

The National Commission on Mathematics and Science Teaching indicates that professional staff development is one of the most effective ways of improving the achievement of K–12 students. The DOE national laboratories clearly are not positioned to affect the hundreds of thousands of STEM educators through direct retraining. However, the laboratories can play a pivotal role in reforming the Nation's STEM education by creating sufficient numbers of highly trained education leaders as agents of change in STEM education. This is accomplished by providing carefully designed mentor-intensive training for science and math educators that will allow them to more effectively teach; to attract their students' interests to science, mathematics, and technology careers; and to improve student achievement. Educators apply on a competitive basis and are matched with mentors working in their subject fields of instruction.

Evaluation includes a self-identification of science content gaps by the educator participant, pre- and post-surveys that benchmark the progress of each participant, successful development of a professional development plan by each educator, results from laboratory self-appraisals, the impact on local STEM education and student achievement; and retention of the educators in STEM K–12 education.

DOE ACTS funded 113 teachers in FY 2008 and will fund 229 educators in FY 2009 (119 continuing and 110 new). The FY 2010 request funds a total of 220 educators (110 continuing and 110 new) and provides master teachers at each participating laboratory.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| | (dollars in thousands) | | |
| **Faculty and Student Teams** | **250** | **1,543** | **1,000** |

Faculty and Student Teams (FaST) provides an opportunity for under-represented faculty and students from colleges and universities to work on a mentor-intensive science research project at a DOE national laboratory. Faculty members are encouraged to return to the laboratory in subsequent summer terms. The program has two key components: faculty professional development designed to encourage faculty with limited research experience to develop grant proposals and participate in DOE/SC programs; and student cohorts who accompany the faculty member. During a 10-week summer research experience at the laboratory, the faculty member is introduced to new and advanced scientific techniques that contribute to their professional development and help them prepare their students for careers in science, engineering, computer sciences, and technology. FaST activities at SC laboratories are being conducted in collaboration with the NSF.

In FY 2009 WDTS launched a major increase in this program tied to the goal of increasing the participation of under-represented faculty and students in SC research programs. Surveys and other evaluation studies have revealed that faculty support of students at the national laboratories is particularly important for Minority Serving Institutions (MSIs), which are primarily teaching institutions and generally do not have the ability to support research activities at their home institutions. The FaST program enables the MSI to build faculty research capabilities, encourages cohorts of diverse students to participate in DOE research, and overall improves the retention and recruitment of under-represented populations in the DOE system.

In FY 2010, all of the undergraduate students supported on FaST teams will be supported through the SULI and CCI programs, enabling an increase in the number of faculty who are supported and maintenance of the mini-grant program. WDTS supported 10 teams in FY 2008, 50 teams in FY 2009, and will support at least 60 teams in FY 2010. Ten faculty and 30 undergraduate students were supported in FY 2008; 50 faculty and 150 undergraduate students in FY 2009; and 60 faculty and 180 students in FY 2010.

| | | | |
|---|---|---|---|
| **Albert Einstein Distinguished Educator Fellowship** | **565** | **1,000** | **1,000** |

The Albert Einstein Distinguished Educator Fellowship Awards for K–12 science, mathematics, and technology educators brings classroom and education expertise to Congress, DOE, and other Federal agencies' education and outreach activities. These educators provide practical insights and "real world" perspectives to policy makers and program managers. The Einstein Fellowship is a valuable professional growth opportunity for the educators because they return to the education field with knowledge of Federal resources and an understanding of national education policies. In FY 2008, WDTS completed an external review of the Einstein Program and, as a result, is making significant program improvements designed to increase the benefits of the program to DOE and to the participants.

In FY 2009, with the organizational support of DOE and other Federal agencies (including NSF, NASA, NOAA, and NIH), WDTS was able to place 15 Einstein Fellows. Of these, 3 were directly supported by WDTS and 1was supported by an Office of Science research program (2 Fellows in Congress and 2 at DOE). The FY 2010 WDTS request will directly support 4 Fellows in Congress and 2 at DOE. The funding will also augment stipends and health insurance for the participants. NSF, NASA, NOAA, and NIH will support 16 Einstein Fellows in FY 2010.

| | | | |
|---|---|---|---|
| **Total, Educator Programs** | **2,664** | **6,311** | **5,750** |

## Explanation of Funding Changes

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| **DOE Academies Creating Teacher Scientists** | |
| The number of educators participating in DOE ACTS will decrease by 9 in FY 2010, from 229 in FY 2009 to 220, beginning a new 3-year cohort, and providing a master teacher at each participating laboratory. | -18 |
| **Faculty and Student Teams** | |
| The number of teams supported by DOE will increase by 10 in FY 2010, from 50 in FY 2009 to 60 because WDTS will fund student participation through the SULI and CCI programs in FY 2010, allowing for an expansion of the number of faculty participants and overall teams. In addition, faculty members will be eligible to participate in a competitive mini-grant program managed by WDTS that enables them to continue DOE research at their home institution. Student participation, through support from the CCI and SULI programs in FY 2010, will increase by 30 in FY 2010 from 150 in FY 2009 to 180. | -543 |
| **Total Funding Change, Educator Programs** | **-561** |

## Workforce Development Programs

### Funding Schedule by Activity

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Workforce Development Programs | | | |
| Graduate Fellowships | — | — | 5,000 |

### Description

WDTS will create the Graduate Fellowship program in FY 2010 at a $5 million level to support 50–60 U.S. students.

Graduate Fellowships fill a compelling need within the DOE workforce development pipeline. Currently, DOE does not have a coordinated fellowship program specifically designed to meet the Nation's long-term workforce needs related to DOE's missions in energy, environment and scientific discovery. A 2008 NSF survey found that of the 2,235 post-doctoral students working at DOE national laboratories, only 889 (40%) were U.S. citizens. This confirms recent studies by the National Academies and other organizations that the U.S. is falling behind other nations in the production of highly qualified technical workers. The Graduate Fellowship program is designed to help remedy this situation and over time will be expanded to support more U.S. Graduate Fellows per year.

### Detailed Justification

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| **Graduate Fellowships** | **—** | **—** | **5,000** |

WDTS will implement the Graduate Fellowship program in FY 2010. The Fellowships will include support for tuition and a stipend for living expenses and travel. Applicants will be competitively selected by external review based on evaluation of each application against established criteria. Outreach will be conducted to all U.S. universities, scientific professional societies, and other organizations with student populations of interest to DOE, with an emphasis on the inclusion of under-represented populations and institutions. The Fellowships will provide up to three years of support over a maximum of five years and will pay for full tuition and fees at a U.S. university, travel associated with the student's research, and an annual stipend. Program evaluation will include pre- and post-surveys of students, as well as longitudinal studies that indicate whether or not the students are finding employment in energy and environment fields important to DOE and the Nation.

| | | | |
|---|---|---|---|
| **Total, Workforce Development Programs** | **—** | **—** | **5,000** |

## Explanation of Funding Changes

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| **Graduate Fellowships** | |
| Implementation of this new Fellowship program will provide 50–60 students with tuition, monthly stipends, and other administrative costs. | +5,000 |

## Program Administration and Evaluation

### Funding Schedule by Activity

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| Program Administration and Evaluation | | | |
| Laboratory Equipment Donation Program | 75 | 75 | 240 |
| Evaluation Studies | 150 | 300 | 200 |
| Technology Development & Online Application | 175 | 400 | 400 |
| Outreach | 200 | 732 | 610 |
| Workforce Studies | 20 | 500 | 300 |
| DOE Mentor Program | — | — | 100 |
| Total, Program Administration and Evaluation | 620 | 2,007 | 1,850 |

### Description

The Program Administration and Evaluation subprogram provides the data, analysis, and other resources required for effective WDTS program management and delivery. Analytical/evaluation studies are used by WDTS program managers to make efficient use of taxpayer dollars. Non-financial resources, such as laboratory equipment or on-line applications, enable WDTS performers and participants to effectively participate in WDTS programs. In addition, WDTS has initiated a number of outreach efforts with universities, professional societies, private industry, and other Federal agencies designed to fully leverage the WDTS investment in workforce development and STEM education programs.

Evaluation Studies and Workforce Studies provide the analytical resources required by WDTS to make informed judgments about the effectiveness and benefits of WDTS program investments. WDTS in FY 2007–2009 developed Evaluation Studies consistent with the recommendations of the Academic Competitiveness Council (ACC)[a] and an OMB/OSTP review. These Evaluation Studies are rigorous reviews of individual performance, program effectiveness, and overall programmatic accomplishment of WDTS goals. Evaluation Studies (pre- and post-surveys, laboratory self-assessments, external expert review, and abstract reviews) focus on six leading indicators of success for WDTS: content knowledge, retention of individuals within the STEM pipeline, quality of the programs, increases in participation by under-represented groups, leveraging, and competition/reward. Workforce Studies identify the long-term STEM workforce needs of DOE and SC, and analyze the long-term success of WDTS programs. WDTS in FY 2007–2008 developed a pilot workforce study/survey methodology that will be fully implemented in FY 2009–2010. These Workforce Studies will identify the critical skill gaps, by scientific discipline, which may exist within the DOE/SC Federal and national laboratory workforces.

The Laboratory Equipment Donation program is being expanded to include middle schools and high schools (currently only universities may participate) so that educators who participate in the DOE ACTS

[a] National Science and Technology Council, Subcommittee on Education, *"Finding Out What Works: Agency Efforts to Strengthen the Evaluation of Federal Science, Technology, Engineering and Mathematics (STEM) Education Programs,"* 2009.

program, the National Science Bowl®, and other K–12 programs can take advantage of DOE's excess equipment donation efforts. The Technology Development and Online Application activity provides the online resources required by students and educators to apply for resources, conduct general outreach, and manage evaluation studies (for example, the educator electronic portfolio). The Outreach activity is designed to reach under-represented populations and to form partnerships with associations, industry, and other groups to leverage WDTS investments. WDTS has developed an outreach strategy focused on the development of closer relationships with under-represented groups and institutions that it will continue to implement in FY 2010. The DOE Mentor Program, a new activity, will solidify DOE's longstanding capacity to recruit, train, and effectively utilize the large cadre of mentor scientists who provide the foundation for WDTS's student and educator programs. This program will develop consistent standards and training for DOE mentors and provide incentives for mentors to participate in all of the WDTS programs. Currently, mentors are recruited and trained by DOE laboratories with very little assistance from WDTS. This limits the number and utility of those mentor scientists because they are not managed as a national resource.

**Selected FY 2008 Accomplishments**

- WDTS initiated the first external peer review of WDTS program management and evaluation efforts in FY 2008. Results of the review were implemented throughout the WDTS portfolio during FY 2008–2009 and will continue to be implemented in FY 2010. A key result was the development of the STEM outreach strategy to under-represented populations and institutions, and greater linkages to SC and DOE R&D programs. Program managers used the results of the external review process to adjust programs and improve program efficiency/effectiveness by reallocating resources to high priority programs (such as FaST) and focusing evaluation efforts on national objectives.
- The first results of the Evaluation Studies were received in FY 2008 and were used to inform program management. One major program adjustment has been the development of competitive solicitation processes for all of WDTS's programs and renewed efforts to improve the diversity of WDTS's programs.
- In FY 2008, more than 568 individual pieces of surplus scientific equipment from DOE national laboratories with an original value of more than $16,304,000 were donated to U.S. universities through the Laboratory Equipment Donation Program.

## Detailed Justification

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| **Laboratory Equipment Donation Program** | **75** | **75** | **240** |

The Laboratory Equipment Donation Program provides excess equipment to faculty at institutions of higher education for energy-related research. Through the Energy Asset Disposal System, DOE sites identify excess laboratory equipment that is then listed on the ERLE website. Colleges and universities can search for equipment of interest to them and apply via the website. DOE property managers approve or disapprove the applications. The equipment is free, but the receiving institution pays for shipping costs. WDTS intends to expand this program in FY 2010 to middle schools and high schools and will pay for shipping costs to those institutions.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| **Evaluation Studies** | **150** | **300** | **200** |

WDTS will sustain rigorous and comprehensive evaluations of all WDTS programs. Funding decreases because initial efforts in FY 2009 have provided a sufficient platform for FY 2010 activities.

| | | | |
|---|---|---|---|
| **Technology Development and On-Line Application** | **175** | **400** | **400** |

Technology Development and Online-Application Systems provides for a new IT architecture, which is a two year endeavor, to enhance and maintain the WDTS application and electronic portfolio system. Funding in FY 2010 will support the second year of the new design of all of the websites, on-line applications, DOE ACTS education portfolios, and pre- and post-surveys that participants complete during their internship/fellowship experiences.

| | | | |
|---|---|---|---|
| **Outreach** | **200** | **732** | **610** |

Outreach has four components: providing information to WDTS program alumni (competitions, undergraduate research internships, educator programs, etc.) to encourage their continued participation in DOE programs; creating a common database of internship opportunities, fellowships, and other research-based educational opportunities at DOE; assisting in the coordination of outreach activities with other Federal agencies; and enhancing communication about WDTS programs to the public. A major emphasis of the outreach effort is with under-represented groups and institutions. In FY 2009 WDTS initiated the development of an outreach strategy that will be implemented in FY 2010.

| | | | |
|---|---|---|---|
| **Workforce Studies** | **20** | **500** | **300** |

Workforce Studies focus on the critical skill gaps, by scientific discipline, which may exist within the SC Federal and national laboratory workforces. These studies are designed to be long-term sustained efforts that will provide a baseline of data and results to effectively manage WDTS programs and set overall strategic direction. Minor funding was provided in FY 2008. Full implementation began in FY 2009 and continues in FY 2010 to provide in-depth and systematic reviews of workforce requirements and to determine the long-term benefits of WDTS program investments by tracking the progress of STEM students and workers who participate in WDTS programs.

| | | | |
|---|---|---|---|
| **DOE Mentor Program** | **—** | **—** | **100** |

The DOE Mentor Program will be implemented in FY 2010 and has two components: a professional development effort designed to recruit and train the mentor scientists at DOE national laboratories and a recognition/rewards program that will provide incentives for mentor participation in WDTS programs. Scientist mentors are the key resource that WDTS bases its programs upon and must be nurtured in a systematic manner to ensure that a sufficient supply of mentors exist for WDTS programs.

| | | | |
|---|---|---|---|
| **Total, Program Administration and Evaluation** | **620** | **2,007** | **1,850** |

### Explanation of Funding Changes

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| **Laboratory Equipment Donation Program** | |
| The increase will support expansion of this program to middle and high schools in FY 2010. Funding will support transportation of equipment to middle and high schools and for some training, as needed. | +165 |
| **Evaluation Studies** | |
| Development efforts for Evaluation Studies occurred in FY 2007–2009 and the reduction reflects the maintenance of the WDTS evaluation program at a sufficient level in FY 2010 to provide in-depth and systemic reviews of all WDTS programs. | -100 |
| **Outreach** | |
| The WDTS STEM outreach strategy identifies a number of new efforts designed to include under-represented individuals and institutions into SC STEM programs. Those include mentor/protégé agreements with Minority Serving Institutions, participation at professional society meetings, and other activities. Funding decreases because initial efforts in FY 2009 have provided a sufficient platform for steady state activities in FY 2010. | -122 |
| **Workforce Studies** | |
| Development efforts for the Workforce Studies began in FY 2008 and were funded in FY 2009 at a level needed to establish the base effort. The reduction reflects maintaining these studies at a sufficient level to provide continuity. | -200 |
| **DOE Mentor Program** | |
| This new effort will create a professional development program focused on mentor/protégé relationships and a rewards/recognition program for outstanding DOE mentors. | +100 |
| **Total Funding Change, Program Administration and Evaluation** | **-157** |

## Supporting Information

### SC Education Crosscut

The Office of Science (SC) through its six research Programs—Basic Energy Sciences, Advanced Scientific Computing Research, Biological and Environmental Research, High Energy Physics, Nuclear Physics, and Fusion Energy Sciences—supports the training of undergraduates, graduate students, and postdoctoral researchers as an integral part of the ongoing sponsored research activities at universities and DOE national laboratories. In addition, these six SC Programs support modest activities targeted towards undergraduate, graduate students, postdocs, and K-12 science and math educators to educate and encourage new talent into fields important to the Program-specific missions.

These activities, in addition to the activities supported within the Workforce Development for Teachers and Scientists program, provide opportunities that will draw U.S. talent into science, technology, engineering and mathematics and create the skilled scientific and technical workforce needed develop the solutions to meeting our energy challenges in the 21st century and enable the U.S. to continue to be among the leaders in science and innovation. The following table summarizes the support for science, technology, engineering, and mathematics education and training opportunities outside of ongoing sponsored research awards.

### Funding Summary

(dollars in thousands)

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| Undergraduate Programs | | | |
| Basic Energy Sciences | 280 | 280 | 300 |
| Advanced Scientific Computing Research | 250 | 250 | 250 |
| Biological and Environmental Research | 100 | 100 | 100 |
| High Energy Physics | 10 | 10 | 10 |
| Nuclear Physics | 73 | 88 | 103 |
| Fusion Energy Sciences | 370 | 370 | 370 |
| Workforce Development for Teachers and Scientists | 3,090 | 3,334 | 5,228 |
| Total, Undergraduate Programs | 4,173 | 4,432 | 6,361 |
| | | | |
| Graduate Programs | | | |
| Basic Energy Sciences | 440 | 578 | 585 |
| Advanced Scientific Computing Research | 5,000 | 5,006 | 6,000 |
| Biological and Environmental Research | 1,694 | 1,703 | 1,710 |
| High Energy Physics | 780 | 780 | 775 |
| Nuclear Physics | 179 | 225 | 167 |
| Fusion Energy Sciences | 1,170 | 1,145 | 1,375 |
| Workforce Development for Teachers and Scientists | — | — | 5,000 |
| Total, Graduate Programs | 9,263 | 9,437 | 15,612 |

| (dollars in thousands) | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| Educator Programs, K–12 Students | | | |
| Biological and Environmental Research | 250 | 250 | 250 |
| High Energy Physics | 750 | 750 | 750 |
| Fusion Energy Sciences | 786 | 850 | 850 |
| Workforce Development for Teachers and Scientists | 4,409 | 8,349 | 8,840 |
| Total, Educator Programs | 6,195 | 10,199 | 10,690 |
| | | | |
| Office of Science | | | |
| Basic Energy Sciences | 720 | 858 | 885 |
| Advanced Scientific Computing Research | 5,250 | 5,256 | 6,250 |
| Biological and Environmental Research | 2,044 | 2,053 | 2,060 |
| High Energy Physics | 1,540 | 1,540 | 1,535 |
| Nuclear Physics | 252 | 313 | 270 |
| Fusion Energy Sciences | 2,326 | 2,365 | 2,595 |
| Workforce Development for Teachers and Scientists | 7,499 | 11,683 | 19,068 |
| Total, Office of Science | 19,631 | 24,068 | 32,663 |

## Safeguards and Security

## Funding Profile by Subprogram

(dollars in thousands)

| | FY 2008 Current Appropriation | FY 2009 Original Appropriation | FY 2009 Additional Appropriation[a] | FY 2010 Request |
|---|---|---|---|---|
| Safeguards and Security | | | | |
| Protective Forces | 33,101 | 34,384 | — | 35,492 |
| Security Systems | 7,862 | 7,940 | — | 8,178 |
| Information Security | 3,977 | 4,028 | — | 4,149 |
| Cyber Security | 16,278 | 19,515 | — | 20,299 |
| Personnel Security | 5,251 | 5,615 | — | 5,767 |
| Material Control and Accountability | 2,284 | 2,348 | — | 2,348 |
| Program Management | 7,193 | 6,773 | — | 6,767 |
| Subtotal, Safeguards and Security | 75,946 | 80,603 | — | 83,000 |
| Less Security Charge for Reimbursable Work | -5,605 | — | — | — |
| Total, Safeguards and Security | 70,341 | 80,603 | — | 83,000 |

**Public Law Authorizations:**
Public Law 95–91, "Department of Energy Organization Act", 1977
Public Law 109–58, "Energy Policy Act of 2005"
Public Law 110–69, "America COMPETES Act of 2007"

## Program Overview

### Mission

The mission of the Office of Science (SC) Safeguards and Security (S&S) program is to support the conduct of Departmental research missions at SC laboratories by ensuring appropriate levels of protection against unauthorized access, theft, diversion, loss of custody, destruction of Department assets, or hostile acts that may cause adverse impacts on fundamental science, national security, the health and safety of DOE and contractor employees, the public, and the environment.

### Background

Prior to FY 2001, S&S activities were funded from overhead accounts at the national laboratories and other facilities. In FY 2001, in an effort to ensure the visibility of safeguards and security, the Department transitioned to a direct-funded approach for S&S activities. Successfully executing the SC mission requires national and international information sharing and open scientific collaboration. SC laboratories have many collaborators, both at the laboratories and internationally through virtual interconnections with universities and research facilities at every corner of the globe. Therefore the SC physical and virtual security posture is required to be cognizant of, flexible, and responsive to efforts to

[a] The Additional Appropriation column reflects the planned allocation of funding from the American Recovery and Reinvestment Act of 2009, P.L. 111–5. See the Department of Energy Recovery website at http://www.energy.gov/recovery for up-to-date information regarding Recovery Act funding.

functionally integrate international research. Furthermore, some laboratories require protection of classified information, and special nuclear material, while others manage irreplaceable Departmental property and the tools of discovery developed for and by scientists worldwide. The S&S program is designed to ensure that the appropriate measures are in place.

**Subprograms**

The functional areas in the S&S program are as follows:

Protective Forces: Security officers/access control officers and security police officers assigned to protect S&S interests.

Security Systems: Personnel, equipment, hardware and software structures, plans and procedures used to protect S&S interests.

Information Security: Execution of the administrative policies and procedures for identifying, marking, and protecting classified and sensitive unclassified information and materials from unauthorized disclosure.

Cyber Security: Protection of computing resources and data against unauthorized access to or modification of information, whether in storage, processing, or transit, as well as ensuring data availability when required for the completion of assigned tasks by Departmental employees.

Personnel Security: Execution of policies, procedures, and activities for granting individuals access to classified matter and/or special nuclear material and for granting Foreign Nationals access to DOE facilities.

Material Control and Accountability: The systems and procedures necessary to establish and track nuclear material inventories, control access to and detect loss or diversion of nuclear material.

Program Management: The policy oversight and administration for the establishment of general requirements for S&S planning for the preceding programs including the reviews of those programs.

**Benefits**

The S&S program protects DOE assets and resources, thereby allowing the programmatic missions of the Department to be conducted in an environment that is secure and based on the unique needs of each site. The Integrated Safeguards and Security Management strategy encompasses a graded approach that enables each facility to design its security protection program to meet the facility and science-specific threat scenario.

## Program Planning and Management

S&S planning and management identifies the resources necessary to ensure protection of Department assets and identifies changes in resource requirements (operational requirements, capital equipment, and general plant projects) and line item construction projects that directly or indirectly impact risk, or derive from changing S&S policy, directives, guidance, or other Departmental direction. In practice planning and management activities include the contractor self assessments, external assessments by the Integrated Support Center, the Department Inspector General, the Department’s Office of Health Safety and Security and reviews by the Science Deputy Director for Field Operations staff office. These audits, inspections and reviews form the basis for tactical and strategic five year plans.

## Budget Overview

In FY 2008 and early FY 2009, the Office of Health, Safety and Security archived more than 20 Departmental directives and replaced them with updated versions of Federal mandates. Additionally, the

Office of the Chief Information Officer archived more than 10 Departmental directives and replaced them with 4 revised and updated requirements manuals. To ensure appropriate and adequate execution of these directives, SC has begun evaluating each site's S&S budget from a requirements-based perspective. These evaluations include a "bottoms-up" analysis of the requirements that apply to each site, identifying the programs necessary to meet those requirements, and the cost for implementing those programs with manageable budgets. This budget request is based on appropriations from prior years. As the detailed evaluation process moves forward, adjustments among functional areas may be needed.

Moreover, a recent collaboration with the laboratory Chief Information Officers produced an action plan to address cyber security requirements consistent with the new Departmental cyber security manuals.

The move towards a requirements-based S&S budget and compliance with new cyber requirements is expected to result in opportunities for improvement and enhanced consistency across SC S&S activities. By FY 2011, SC expects to have the requirements-based approach fully implemented at our laboratories.

## Detailed Justification

(dollars in thousands)

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **Ames Laboratory** | **944** | **974** | **980** |

Ames Laboratory is operated as an open site; and additional access restrictions and protection strategies are applied according to the Laboratory's site security plan. The integration of the Ames Laboratory with the buildings and activities of Iowa State University has implications for site security planning and site utilization.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **Argonne National Laboratory** | **8,562** | **8,514** | **8,694** |

Argonne National Laboratory has been allocated adequate funding through Environmental Management to begin clean up of a significant quantity of safeguards interests. These interests will require greater levels of protection and material control and accountability during transition.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **Brookhaven National Laboratory** | **10,859** | **11,349** | **11,530** |

The threat spectrum for Brookhaven National Laboratory is based upon the current DOE Graded Security Protection Policy for DOE programs and facilities as well as other threat/risk assessments conducted by the laboratory and the Federal Bureau Investigation. Further, the Suffolk County Police Department has identified the laboratory as one of the highest likely targets of an attack and includes it on their "Critical Infrastructure List". The laboratory's protection strategies consider the highly capable adversaries associated with the Department's lowest facility protection category as well as those indentified in local risk and threat documents.

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **Chicago Office** | **1,992** | **1,600** | **—** |

FY 2008 funding included HSPD-12 implementation which is now under All Other. Also, FY 2008 and FY 2009 funding provided for protective force services at Fermi National Accelerator Laboratory which is transferred to the laboratory in FY 2010, consistent with the contract period.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| **Fermi National Accelerator Laboratory** | **2,201** | **1,734** | **3,383** |

As a basic science research laboratory facilitating scientific excellence, Fermi National Accelerator Laboratory is engaged in providing unclassified, open and collaborative work environments. The increase is a result of the transfer of responsibility from the Chicago Office to the laboratory for access control officers/security officers.

| | | | |
|---|---|---|---|
| **Lawrence Berkeley National Laboratory** | **4,985** | **5,006** | **5,059** |

The laboratory serves a large community of continental and intercontinental visitors. Consistent with the terms of the contract with the University of California, no sensitive or classified research is conducted by laboratory or allowed on site. S&S funding supports secure but open collaborative efforts on- and off-site.

| | | | |
|---|---|---|---|
| **Oak Ridge Institute for Science and Education** | **1,679** | **1,617** | **1,626** |

The S&S program implements a comprehensive, graded-approach strategy for the protection of DOE assets. With the exception of three limited security areas which afford protection of classified matter up to and including the Secret Restricted Data level, all the facilities are designated as property protection areas for the purpose of protecting other government owned assets.

| | | | |
|---|---|---|---|
| **Oak Ridge National Laboratory** | **7,652** | **8,895** | **8,895** |

The S&S budget supports the laboratory in its role as a world-leader in scientific research, emerging technologies, and national security research. The site is a Department of Homeland Security Laboratory with the anticipation of research roles particularly in areas related to detection, inhibition, and response to the use of unconventional weapons and radiation dispersal devices in the United States.

| | | | |
|---|---|---|---|
| **Oak Ridge Office** | **18,649** | **18,699** | **19,237** |

The Oak Ridge Office oversees and manages S&S programs at three primary sites in Tennessee—the Oak Ridge National Laboratory, the East Tennessee Technology Park, and the Oak Ridge Institute for Science and Education. This request primarily provides funding for protective forces for these sites.

| | | | |
|---|---|---|---|
| **Office of Scientific and Technical Information** | **630** | **490** | **490** |

The Office of Scientific and Technical Information's mission is to collect, preserve, disseminate, and leverage the scientific and technical information resources of DOE to expand the knowledge base of science and technology and facilitate scientific discovery and application. S&S funding supports classified information protection and unclassified cyber security controls. This request continues to maintain a secure architecture with controls to protect DOE’s electronic R&D information.

| | | | |
|---|---|---|---|
| **Pacific Northwest National Laboratory** | **11,153** | **11,163** | **11,163** |

The laboratory manages an inventory of special nuclear materials and is approved to possess classified matter. The laboratory is a cyber center of excellence for National research and development efforts. Funding for protective force operations is the responsibility of the Office of Environmental Management.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| **Princeton Plasma Physics Laboratory** | **2,368** | **2,075** | **2,104** |

Princeton Plasma Physics Laboratory is effectively integrated with the security controls implemented by Princeton University and separated for implementation of the Department's required and enhanced security controls. The laboratory is considered a property protection area. The resident Tritium inventory is located in four areas within a secured perimeter and restricted access controlled area.

| | | | |
|---|---|---|---|
| **SLAC National Accelerator Laboratory** | **2,566** | **2,558** | **2,615** |

The security interests for SLAC include protection in designated property protection areas for persons and Departmental property. The remainder of the site is an open extension of the Stanford University campus. Consistent with the terms of the contract with Stanford University, no sensitive or classified research is conducted by SLAC or allowed on-site.

| | | | |
|---|---|---|---|
| **Thomas Jefferson National Accelerator Facility** | **1,626** | **1,325** | **1,346** |

Entry to the laboratory is controlled to limit entry to individuals who have an official purpose at the research facility. No areas are defined as security areas; security interests are protected by employing protection strategies. Unclassified sensitive information requiring protection is controlled by employees who are in possession of the documents or information technology system. High Risk personal property is protected by the employee custodian of the property.

| | | | |
|---|---|---|---|
| **All Other** | **80** | **4,604** | **5,878** |

All Other supports the continuation and management of a consistent cyber security approach across the Office of Science laboratory complex and program management needs for SC. Funding will be allocated based on the highest priority needs following the scheduled programmatic reviews.

| | | | |
|---|---|---|---|
| **Subtotal, Safeguards and Security** | **75,946** | **80,603** | **83,000** |
| **Less Security Charge for Reimbursable Work** | **-5,605** | **—** | **—** |
| **Total, Safeguards and Security** | **70,341** | **80,603** | **83,000** |

## Explanation of Changes

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| **Ames Laboratory** | |
| Funding is provided for a constant level of effort for access control/security officer services. | +6 |
| **Argonne National Laboratory** | |
| Funding is provided for a constant level of effort for access control/security officer services. | +180 |
| **Brookhaven National Laboratory** | |
| Funding is provided for a constant level of effort for protective forces officer services. | +181 |

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| **Chicago Office** | |
| Access control/security officer funding is transferred to Fermi National Accelerator Laboratory, consistent with the contract period. | -1,600 |
| **Fermi National Accelerator Laboratory** | |
| Funding is transferred from the contracted access control/security officer services and to maintain a constant level of effort. | +1,649 |
| **Lawrence Berkeley National Laboratory** | |
| Funding is provided for a constant level of effort for access control/security officer services. | +53 |
| **Oak Ridge Institute for Science and Education** | |
| Funding is provided for a constant level of effort for access control/security officer services. | +9 |
| **Oak Ridge Office** | |
| Funding is provided for constant level of effort for protective force services. | +538 |
| **Princeton Plasma Physics Laboratory** | |
| Funding is provided for a constant level of effort for access control/security officer services. | +29 |
| **SLAC National Accelerator Laboratory** | |
| Funding is provided for a constant level of effort for access control/security officer services. | +57 |
| **Thomas Jefferson National Accelerator Facility** | |
| Funding is provided for a constant level of effort for access control/security officer services. | +21 |
| **All Other** | |
| The Office of Science will review priority basis requests in alignment with specific security enhancements. The end of life security systems issues will be evaluated against sustainability at each laboratory and viability of alternatives. Also, the requests for cyber security enhancements will be evaluated against the requirements for all SC S&S areas. | +1,274 |
| **Total Funding Change, Safeguards and Security** | **+2,397** |

## Supporting Information

## Operating Expenses, Capital Equipment and Construction Summary

(dollars in thousands)

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| Operating Expenses | 74,286 | 80,603 | 83,000 |
| Capital Equipment | 960 | — | — |
| General Plant Projects | 700 | — | — |
| Subtotal, Safeguards and Security | 75,946 | 80,603 | 83,000 |
| Less Security Charge for Reimbursable Work | -5,605 | — | — |
| Total, Safeguards and Security | 70,341 | 80,603 | 83,000 |

## Congressionally Directed Projects

### Funding Profile by Subprogram

(dollars in thousands)

| | FY 2008 Current Appropriation | FY 2009 Original Appropriation | FY 2010 Request |
|---|---|---|---|
| Congressionally Directed Projects | | | |
| Congressionally Directed Projects | 120,161 | 91,064 | — |
| SBIR/STTR | — | 2,623 | — |
| Total, Congressionally Directed Projects | 120,161[ab] | 93,687 | — |

### Description

The Energy and Water Development and Related Agencies Appropriations Act, 2009 included 68 congressionally directed projects within the Office of Science. Funding for these projects was appropriated as a separate funding line although specific projects may relate to ongoing work in other programmatic areas.

### Detailed Justification

(dollars in thousands)

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| **Congressionally Directed Projects** | | | |
| ▪ Advanced Artificial Science and Engineering Research Infrastructure (TX) | — | 370 | — |
| ▪ Advanced Cellular and Biomolecular Imaging (PA) | 479 | — | — |
| ▪ Advanced Laboratory Technology Initiative (NJ) | 479 | — | — |
| ▪ Alabama A&M University Research Institute Integrated Environmental Research and Services (AL) | 479 | — | — |
| ▪ Albright College Science Facilities (PA) | 334 | — | — |
| ▪ Alliance for NanoHealth (TX) | 717 | — | — |
| ▪ Alvernia College Scientific Instrumentation Initiative (PA) | — | 555 | — |
| ▪ Barry University Institute for Collaborative Sciences Research (FL) | 383 | 740 | — |
| ▪ Belmont Bay Science Center (VA) | 239 | — | — |
| ▪ Bennett College Science and Technology Facility (NC) | 956 | — | — |
| ▪ Berkshire Enviromental Resources Center (MA) | 239 | — | — |

[a] Reflects a reduction for the 1.6% rescission in P.L. 110–161, the Energy and Water Development and Related Agencies Appropriations Act, 2008.
[b] Total is reduced by $3,462,000; $3,091,000 of which was transferred to the Small Business Innovative Research (SBIR) program; and $371,000 of which was transferred to the Small Business Technology Transfer (STTR) program.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| ▪ Bionanotechnology: Research and Commercialization, Louisiana Tech University, Ruston (LA) | — | 1,387 | — |
| ▪ Biotechnology/Forensics Laboratory (UT) | — | 462 | — |
| ▪ Boston College Institute for Integrated Sciences (MA) | 956 | 2,312 | — |
| ▪ Bronx Community College Center for Sustainable Energy (NY) | 287 | 462 | — |
| ▪ Brown University, Brown Energy Initiative (RI) | — | 925 | — |
| ▪ Bulk Production of Metallic Glass (OH) | 479 | — | — |
| ▪ California State University, San Bernardino Twin Tower Project (CA) | — | 555 | — |
| ▪ Cardiac Catheterization Research and Equipment (TX) | 717 | — | — |
| ▪ Center for Catalysis and Surface Science At Northwestern University (IL) | — | 925 | — |
| ▪ Center for Diagnostic Nanosystems, Marshall University, Huntington (WV) | — | 1,850 | — |
| ▪ Center for Nanomedicine and Cellular Delivery, School of Pharmacy, University of Maryland, Baltimore (MD) | — | 694 | — |
| ▪ Center for Nanomedicine at the University of Maryland in Baltimore to Support Research into New Nanoconstructs (MD) | 239 | — | — |
| ▪ Center of Excellence and Hazardous Materials, Carlsbad (NM) | — | 1,850 | — |
| ▪ Chemistry Building Renovation (MI) | — | 462 | — |
| ▪ Cheyney University STEM Education Infrastructure (PA) | 1,195 | — | — |
| ▪ Chicago Public Schools Science Laboratory Enhancement (IL) | 956 | — | — |
| ▪ Chicago State University Research (IL) | 956 | — | — |
| ▪ Children’s Oncology Group Childhood Cancer Research (TX) | 191 | — | — |
| ▪ Clemson University Cyberinstitute (SC) | — | 1,387 | — |
| ▪ Climate Change Modeling Capability, Los Alamos National Laboratory, Los Alamos (NM) | — | 4,625 | — |
| ▪ Clinton Junior College Science Program (SC) | — | 370 | — |
| ▪ Coe College Scientific Instrumentation (IA) | 861 | — | — |
| ▪ Columbus Children’s Hospital Imaging Equipment (OH) | 956 | — | — |

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| ▪ Contrast Media and Wound Closure Reduction Study, University of Mississippi (MS) | — | 601 | — |
| ▪ Curriculum and Infrastructure Enhancement in STEM (PA) | — | 462 | — |
| ▪ Decision Support Tools for Complex Analysis (DSTCA) (OH) | 1,913 | 1,387 | — |
| ▪ DePaul University Interdisciplinary Science and Technology (IL) | 239 | — | — |
| ▪ Dominican University in River Forest, Illinois for Research Related to the Role of Transglutaminases in Alzheimer's and Huntington's Diseases (IL) | 573 | — | — |
| ▪ Eastern Kentucky University Chemical Research Instrumentation (KY) | 287 | — | — |
| ▪ Eastern Kentucky University Equipment for New Science Building (KY) | — | 925 | — |
| ▪ Eckerd College Science Center (FL) | 1,913 | — | — |
| ▪ Emmanuel College Center for Science Partnership (MA) | 479 | — | — |
| ▪ Energy Efficiency through the NY Industrial Retention Network (NY) | 479 | — | — |
| ▪ Environmental System Center at Syracuse University (NY) | 717 | — | — |
| ▪ Facilitating blood-brain barrier research, Seattle Science Foundation, Seattle (WA) | — | 1,387 | — |
| ▪ Fordham University Regional Science Center (NY) | 670 | — | — |
| ▪ Former Workers Medical Surveillance Programs, State University of Iowa, Iowa City (IA) | — | 925 | — |
| ▪ Functional MRI Science Research, University of Vermont College of Medicine, Burlington (VT) | 956 | 1,156 | — |
| ▪ Fusion Energy Spheromak Turbulent Plasma Experiment (FL) | — | 925 | — |
| ▪ George Mason University – National Center for Biodefense and Infectious Disease (VA) | — | 1,387 | — |
| ▪ Geothermal Demonstration Project (OH) | 479 | — | — |
| ▪ Geothermal System at Sherman Hospital in Elgin, IL (IL) | 956 | — | — |
| ▪ Germantown Biotechnology Project (MD) | 1,435 | — | — |
| ▪ Good Samaritan Hospital Specialty Cancer Center (OH) | 383 | — | — |
| ▪ Green Building Technologies for Lakeview Museum (IL) | 191 | — | — |
| ▪ Green Energy Xchange (NC) | 803 | — | — |

| (dollars in thousands) | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ Gulf of Maine Research Institute Laboratory Upgrades (ME) | 717 | — | — |
| ▪ Harney Science Center Equipment (CA) | 479 | — | — |
| ▪ Hofstra University Center for Condensed Matter Research (NY) | 525 | — | — |
| ▪ Hofstra University Center of Climate Study (NY) | — | 462 | — |
| ▪ Idaho Accelerator Center Production of Medical Isotopes (ID) | — | 925 | — |
| ▪ Idaho National Laboratory Center for Advanced Energy Studies (ID) | — | 2,429 | — |
| ▪ Imaging and Oncology Equipment at Utah Valley State College (UT) | 717 | — | — |
| ▪ Indiana Wesleyan University School of Nursing (IN) | 239 | — | — |
| ▪ Inland Northwest Research Alliance (INRA) Water Research (WA) | 1,435 | — | — |
| ▪ Instrumentation and Construction Costs for Three Students Independent Research Labs Dedicated to Biology, Chemistry and Biochemistry, and Physics at Albright College in Reading (PA) | — | 370 | — |
| ▪ Intermountain Center for River Restoration and Rehabilitation, Utah State University, Logan (UT) | — | 555 | — |
| ▪ Jackson State University in Jackson, Mississippi, for Bioengineering Research Training (MS) | 1,913 | — | — |
| ▪ Jacksonville University Marine Science Research Institute (FL) | 479 | — | — |
| ▪ Lake Granbury and Lake Whitney Assessment (TX) | 479 | — | — |
| ▪ Lapeer Regional Medical Center Computerized Tomagraphy Simulator (MI) | 383 | — | — |
| ▪ Levine Children's Hospital Computerized Tomagraphy Scanner (NC) | 956 | — | — |
| ▪ Lightweight Power Supply Development (PA) | 479 | — | — |
| ▪ Logan Cancer Center Equipment and Technology (UT) | 956 | — | — |
| ▪ Loma Linda University Medical College Radiation Protection Program (CA) | 1,913 | — | — |
| ▪ Louisiana Tech University in Ruston, Louisiana, for Research in Nanotechnology (LA) | 1,435 | — | — |
| ▪ Louisville Science Center (KY) | 144 | — | — |

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| ▪ Luther College Science Building, Renovation Project (IA) | 717 | 925 | — |
| ▪ Marine Systems Research, University of Massachusetts at Boston (MA) | 479 | 462 | — |
| ▪ Marygrove College Matters (MI) | — | 185 | — |
| ▪ Materials and Energy Research Development, Tulane University, New Orleans (LA) | 1,147 | 925 | — |
| ▪ Mathematics, Science and Technology Research and Training Lab Project (PA) | 2,391 | — | — |
| ▪ Matter-Radiation Interactions in Extremes, Los Alamos National Laboratory, Los Alamos (NM) | — | 6,474 | — |
| ▪ Memorial Health System, Springfield, Illinois (IL) | 479 | — | — |
| ▪ Memorial Hermann Baptist Hospital Orange—1.5 Tesla Magnetic Resonance Imaging (TX) | 573 | — | — |
| ▪ Michigan Geological Carbon Sequestration Research and Education Program (MI) | — | 601 | — |
| ▪ Nanosystems Initiative at the University of Rochester (NY) | 956 | — | — |
| ▪ Nanotechnology Research Internships in Illinois (IL) | 479 | — | — |
| ▪ National Biorepository—Nationwide Children’s Hospital (OH) | — | 694 | — |
| ▪ Neuroscience Research, Dominican University, River Forest (IL) | 287 | 462 | — |
| ▪ Neurosciences Institute in Morgantown, West Virginia, to Support Molecular Genetics Research (WV) | 1,913 | — | — |
| ▪ Nevada Cancer Institute in Las Vegas to Support Research of Cellular Antigens and Nuclei Acids (NV) | 479 | — | — |
| ▪ New Mexico Center for Isotopes in Medicine (NM) | 717 | — | — |
| ▪ New Mexico Tech University in Socorro, New Mexico, for Applied Energy Science Design (NM) | 1,435 | — | — |
| ▪ New School University Green Building (NY) | 1,913 | — | — |
| ▪ Next Generation Neuroimaging at Cleveland Clinic (OH) | — | 462 | — |
| ▪ North Dakota State University Computing Capability, Fargo (ND) | — | 5,550 | — |
| ▪ Northern Hemisphere Pierre Auger Observatory in Colorado for the Northern Hemisphere Location of a Particle Detection Observatory (CO) | 956 | — | — |

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| ▪ Northwest Missouri State University in Maryville, Missouri, for the Nanoscience Education Project (MO) | 1,147 | — | — |
| ▪ Notre Dame Innovation Park (IN) | 750 | — | — |
| ▪ Nutley Energy Efficient Elementary Schools (NJ) | 479 | — | — |
| ▪ Perry Memorial Hospital Picture Archiving and Communicating System (IL) | 334 | — | — |
| ▪ Phase II Design and Construction of Sage Hall Science (FL) | 479 | — | — |
| ▪ Pikeville Medical Center, Kentucky (KY) | 479 | — | — |
| ▪ Pioneer Valley Life Sciences Institute Biomedical Research, Pioneer Valley Life Science Institute, Springfield (MA) | 956 | 462 | — |
| ▪ Professional Science Master's Advanced Energy and Fuels Management Program (IL) | — | 416 | — |
| ▪ Purdue Calumet Inland Water Institute (IN) | 479 | 925 | — |
| ▪ Purdue Technology Center (IN) | 1,913 | — | — |
| ▪ Rapid Detection of Contaminants in Water Supplies Using Magnetic Resonance and Nanoparticles (MA) | — | 1,387 | — |
| ▪ Regenerative Medicine (IL) | — | 462 | — |
| ▪ Research into Proton Beam Therapy, Seattle Cancer Care Alliance, Seattle (WA) | 717 | 1,387 | — |
| ▪ RNAI Research, University of Massachusetts Medical School, Worcester (MA) | — | 925 | — |
| ▪ Rockland Community College Science Laboratory (NY) | 479 | — | — |
| ▪ Roosevelt University Biology Laboratory Equipment (IL) | 670 | — | — |
| ▪ Saint Clare's Hospital (NJ) | 479 | — | — |
| ▪ Saint Joseph's University Science Center Equipment (PA) | 765 | — | — |
| ▪ Saint Rose Dominican Hospitals Sienna Trauma Center (NV) | 479 | — | — |
| ▪ Sandia Institute for Advanced Computing Algorithms, New Mexico, for High Performance Computing and Advanced Algorithm Development (NM) | 7,114 | — | — |
| ▪ Sandia Nanotechnology Engineering Center, Sandia National Laboratory, Albuquerque (NM) | — | 4,625 | — |
| ▪ Scanning Near-Field Ultrasound Holography (SNFUH) Instrumentation for Non-Invasive And: Non-Destructive Imaging of Nanoparticle Interaction with Cells (IL) | — | 925 | — |
| ▪ Science Education Facility Renovations, OCO (OH) | — | 925 | — |

(dollars in thousands)

| | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ Science, Math, and Technology Education Initiative College of St. Elizabeth (NJ) | — | 462 | — |
| ▪ Seton Hall University Science and Technology Center (NJ) | 956 | — | — |
| ▪ South Carolina Lambda Rail Computer Network Portal (SC) | 1,147 | — | — |
| ▪ South County Nature Preserve, Irvington, NY (NY) | 239 | — | — |
| ▪ South Dakota Catalyst Group for Alternative Energy to Support Research that will Synthesize, Characterize and Scale Up Production of Catalysts Important for Energy Alternatives to Fossil Fuels (SD) | 1,052 | — | — |
| ▪ Southern Methodist University Advanced Parallel Processing Center (TX) | — | 925 | — |
| ▪ SPECT Imaging Instrumentation Research Initiative (IL) | — | 925 | — |
| ▪ St. Thomas University–Community Outreach, Research and Training Endeavor (FL) | 239 | 555 | — |
| ▪ Supercapacitors (NY) | — | 1,387 | — |
| ▪ Sustainable Biofuels Development Center, Colorado State University, Fort Collins (CO) | 334 | 1,387 | — |
| ▪ Technology for Print Disabled Students (FL) | 1,147 | — | — |
| ▪ Texas Center for Advanced Scientific Computing and Modeling (TX) | 717 | 681 | — |
| ▪ The Methanol Economy (CA) | 1,913 | — | — |
| ▪ The National Energy Policy Institute, University of Tulsa (OK) | — | 694 | — |
| ▪ Ultra-Dense Porphyrim-Based Capacity Molecular Memory For Supercomputing (CO) | — | 925 | — |
| ▪ Ultra-Dense Supercomputing Memory Storage in Colorado for Further Research in this Field (CO) | 956 | — | — |
| ▪ University of California, Los Angeles for the Institute for Molecular Medicine Radiation Research (CA) | 5,738 | — | — |
| ▪ University of California, San Diego to Support Seismic Research (CA) | 1,913 | — | — |
| ▪ University of Chicago to Research Multi-Modality, Image-Based Markers for Assessing Breast Density and Structure to Determine Risk of Breast Cancer (IL) | 573 | — | — |
| ▪ University of Dubuque, Environmental Science Center (IA) | 956 | — | — |

| (dollars in thousands) | FY 2008 | FY 2009 | FY 2010 |
|---|---|---|---|
| ▪ University of Kansas Medical Center Tele-Oncology Network (KS) | 287 | — | — |
| ▪ University of Louisville Regional NMR Facility in Louisville, Kentucky, to Support Ongoing Research in Fundamental Processes of Electron Transport Systems and the Structural Biology of Proteins (KY) | 956 | — | — |
| ▪ University of Maine in Orono, Maine, for Research in Integrated Forest Products Refinery Technology (ME) | 956 | — | — |
| ▪ University of Massachusetts Integrative Science Building (MA) | 1,913 | 1,850 | — |
| ▪ University of Mississippi Medical Center in Jackson, Mississippi, to Fund Research in the Areas of Increasing Efficiency by Reducing the Amount of Contrast Media Needed for Certain Procedures (MS) | 573 | — | — |
| ▪ University of Nebraska Medical Center in Omaha to Conduct Nanoscale Imaging of Proteins (NE) | 1,913 | — | — |
| ▪ University of Nevada, Las Vegas, Nevada Water in the 21st Century Multi-Disciplinary Research Project (NV) | 956 | — | — |
| ▪ University of New Mexico in Albuquerque, New Mexico, for the Mental Illness and Neuroscience Discovery (MIND) Institute Ongoing Research into Brain Related Research Including Supporting Research of Military Personnel Suffering from Post Traumatic Stress Disorder, Depression and Traumatic Brain Injuries (NM) | 11,478 | 11,099 | — |
| ▪ University of North Carolina Collaborative Initiative in Biomedical Imaging (NC) | 956 | 1,387 | — |
| ▪ University of North Dakota Research Foundation, in Grand Forks to Support Antibodies Research (ND) | 2,391 | 2,544 | — |
| ▪ University of Oklahoma in Norman Oklahoma, for the Large Scale Application of Single-Walled Carbon Nanotubes (OK) | 956 | 925 | — |
| ▪ University of Saint Francis Science Center (IN) | 689 | — | — |
| ▪ University of South Alabama Cancer Institute Oncology Medical Record System (AL) | 479 | — | — |
| ▪ University of Southern Indiana Engineering Equipment (IN) | 717 | — | — |
| ▪ University of the Cumberlands Science and Technology Complex (KY) | — | 925 | — |
| ▪ University of Vermont in Burlington to Support Research in Agricultural, Environmental, and Biological Sciences (VT) | 2,869 | — | — |

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2008 | FY 2009 | FY 2010 |
| ▪ Urban Research Center and Greenhouse, Brooklyn (NY) | 479 | — | — |
| ▪ University of Rhode Island Cyberinfrastructure (RI) | — | 925 | — |
| ▪ Wake Forest University Research on Alternatives to Transplantation (NC) | 956 | — | — |
| ▪ Waste Isolation Pilot Plant in Carlsbad, New Mexico, to Support Neutrino Research (NM) | 1,435 | — | — |
| ▪ Westminster College Science Center (UT) | 383 | — | — |
| ▪ Whittier College Science and Mathematics Initiative (CA) | — | 462 | — |
| ▪ Xavier University Science Equipment (OH) | 479 | — | — |
| **Total, Congressionally Directed Projects** | **120,161** | **91,064** | **—** |
| **SBIR/STTR** | **—** | **2,623** | **—** |

In FY 2008, $3,091,000 and $371,000 were transferred to the SBIR and STTR programs, respectively. FY 2009 amount shown is the estimated requirement for continuation of the SBIR and STTR programs that are mandated by congress.

| | | | |
|---|---|---|---|
| **Total, Congressionally Directed Projects** | **120,161** | **93,687** | **—** |

**Explanation of Funding Changes**

| | FY 2010 vs. FY 2009 ($000) |
|---|---|
| **Congressionally Directed Projects** | |
| No FY 2010 funding is requested | -91,064 |
| **SBIR/STTR** | |
| No FY 2010 funding is requested | -2,623 |
| **Total Funding Change, Congressionally Directed Projects** | **-93,687** |

## Isotope Production and Distribution Program Fund

### Program Overview

No funds are requested for the Isotope Production and Distribution Fund (Isotope Program). Each of the sites' production expenses for processing and distributing isotopes is offset by revenue generated from sales. See the Isotope Production and Applications section of the Nuclear Physics program within the Science appropriation for justification of the direct appropriations requested.

Isotopes are currently produced and processed at three facilities: Los Alamos National Laboratory, Brookhaven National Laboratory, and Oak Ridge National Laboratory. In addition, the Isotope Program is planning to use the recently installed hydraulic tube at the Advanced Test Reactor (ATR) at the Idaho National Laboratory (INL). This upgrade will provide additional capability to produce short-lived medical and scientific research isotopes in short supply. At the Pacific Northwest National Laboratory (PNNL), the isotope program will continue to distribute strontium-90, a byproduct material. For the future, the Isotope Program will consider processing other byproduct material stored at PNNL. The Isotope Program will also consider production capabilities at university facilities in the future.

### Background

The Isotope Program produces and sells radioactive and stable isotopes, byproducts, surplus materials, and related isotope services world wide. The Isotope Program operates under a revolving fund established by the 1990 Energy and Water Appropriations Act (Public Law 101-101), as modified by Public Law 103-316. In FY 2008, research isotopes were priced based on direct production costs. The Isotope Program is in the process of developing new pricing policies for research isotopes to make them more affordable to the research community. The DOE will continue to sell commercial isotopes at full-cost recovery.

The Program's fiscal year appropriation will be received via transfer from the Nuclear Physics program starting in FY 2009. Prior to FY 2009, the direct appropriation was provided via transfer from the Radiological Facilities Management program within the Office of Nuclear Energy. The appropriation funds the scientists and engineers needed to support the isotope program, and to operate, improve and maintain isotope facilities needed to assure reliable and enhanced production. In addition, the appropriation provides for support of R&D activities associated with the development of new production and processing techniques for isotopes; operations support for the production of research isotopes; and support for the training of new personnel in isotope production and development.

The combination of the annual direct appropriation and revenues from isotope sales are deposited in the Isotope Production and Distribution Program Fund, the revolving fund. The fund's revenue and expenses are audited annually consistent with Government Auditing Standards and other relevant acts, such as the Chief Financial Officers Act of 1990 and the Government Performance and Results Act of 1993.

The Department has supplied isotopes and related services for more than 50 years. These isotope products and services are used by medical institutions, universities, research organizations, and industry for a wide array of uses and applications. They will also provided to many Federal agencies either directly or indirectly, including the National Institutes of Health and its grantees, the Environmental Protection Agency, and the Department of Homeland Security.

As the range of available isotopes and the recognized uses for them have increased, new or improved isotope products have contributed to progress in medical research and practice, new industrial processes, and scientific investigation. Substantial national and international infrastructure has been built around the use of isotopes and is dependent on the Department's products and services. Isotopes are used for hundreds of research, biomedical, homeland security, and industrial applications that benefit society every day, including heart imaging, cancer therapy, smoke detectors, neutron detectors, explosive detection, oil exploration, and tracers for climate change.

Isotope applications are widely used in medical research, diagnosis, and therapies, which are a growing component of the U.S. health care system. The use of medical isotopes reduces health care costs and improves the quality of patient care. It is estimated that for one in every three people treated at a hospital, their treatment makes use of a radioisotope in their laboratory tests, diagnoses, or therapy. Each day, over 40,000 medical patients receive nuclear medicine procedures in the United States. Such nuclear procedures are among the safest diagnostic tests available. They save many millions of dollars each year in health care costs and enhance the quality and effectiveness of patient care by avoiding costly exploratory surgery and similar procedures. For example, it has been demonstrated that the use of myocardial perfusion imaging in emergency department chest pain centers can reduce the duration of stay on average from 46 hours to 12 hours. Therefore, an adequate supply of medical and research isotopes is essential to the Nation's health care system, and to basic research and industrial applications that contribute to national economic competitiveness.

Isotope uses in homeland security applications are also increasing, and include: radiation portal monitors used to find unshielded or lightly shielded radiological material; imaging systems used to find densely shielded material; systems to detect the presence of nitrogen-based chemical explosives; and other forms of explosive detection.

**FY 2008 Accomplishments**

In FY 2008, the Isotope Program served over 190 customers including major pharmaceutical companies such as GE Healthcare and Siemens Medical Solutions; industrial users such as Spectra Gases and Frontier Technology; and hundreds of researchers at hospitals, national laboratories, universities, and private companies. There are ten high volume isotopes among the many produced by the Program. The remaining ones are low-volume, high-cost research isotopes. Generally, program sales projections are dynamic and require frequent modification. For example, over the last three years, the demand for the Department's medical isotopes has increased by more than 15%. In FY 2008, there were a total of 562 shipments made of which 25% were foreign and 4% were intra-governmental. Customer satisfaction with product specifications continues to be high. The Isotope Program ensured 100% of products and services provided met the terms of the contract/sales order.

A loss of sponsorship of the Cf-252 production program at the High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory (ORNL) almost forced a cessation in production, as the Isotope Program could not afford to support the effort single-handedly. The Program investigated the Cf-252 cost issues and worked with ORNL staff to optimize production efficiency and minimize costs. The Program met several times with industrial representatives to understand and project long-term needs and availability of Cf-252. A path forward for ensuring future production of Cf-252 for the Nation was successfully identified.

## Budget Overview

For FY 2010 and the future, the Department foresees more than moderate growth in isotope demand, coupled with the possible need for new isotope products for homeland security, medicine, and industry. In order to satisfy the needs of its customers, the program seeks to meet supply requirements for year-round availability of isotopes for scientific and medical research and, in particular, for human clinical trials. The program's production capability may be called upon for initial ramp-up of production of major new isotope products until market forces bring in private producers that are willing to invest and produce the needed isotopes.